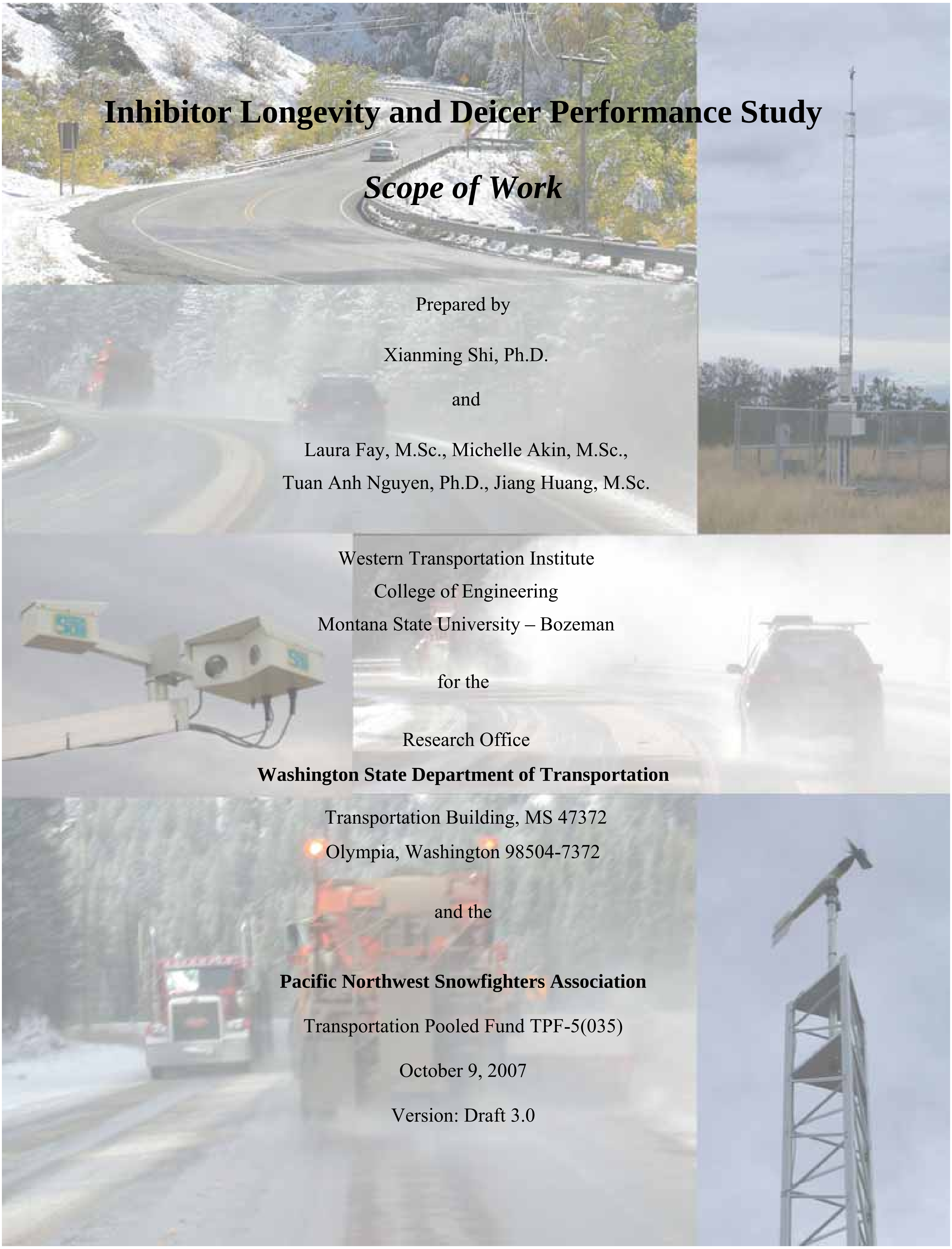

Inhibitor Longevity and Deicer Performance Study

Scope of Work

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1. Problem Statement

In cold-climate regions such as the northern U.S. and Canada, large amounts of solid and liquid chemicals (known as deicers[1]) as well as abrasives are applied onto winter highways to keep them clear of ice and snow. Deicers (mainly sodium chloride [NaCl], magnesium chloride [$MgCl_2$], and calcium chloride [$CaCl_2$]) can be found in a wide variety of snow and ice control products used on winter highways to either prevent the bonding of ice to the roadway (anti-icing) or break the bond between ice and the roadway (de-icing). Prior to application onto roadways, liquid salts are also added to abrasives or solid salts to make them easier to manage, distribute, and stay on roadways (pre-wetting).

Transportation agencies are under increasing pressure to maintain high levels of safety and mobility even during the winter months, while working with limited financial and staffing resources and recognizing the environmental challenges related to chemical and material usage (1, 2, 3, 4). The U.S. spends $2.3 billion annually to keep roads clear of snow and ice (5); in Canada, more than $1 billion is spent annually on winter maintenance (6). WSDOT typically spends $25-30 million dollars for winter maintenance operations, and millions of pounds of deicers (mainly corrosion-inhibited NaCl, $MgCl_2$ and $CaCl_2$) are applied on the roadways every winter.

With professionals from the transportation agencies in the States of Washington, Oregon, Montana, Idaho, Colorado and British Columbia, the Pacific Northwest Snowfighters (PNS) Association has become a recognized pioneer in establishing and standardizing chemical products for snow and ice control. In the PNS Qualified Product List, deicers (Categories 1, 2, 4, 5, and 6) are often required to be inhibited to reduce their corrosivity. Laboratory tests indicate corrosive effects can be reduced by at least 70 percent with the addition of inhibitors. The inhibitors are organic (typically carbohydrates, which are biodegradable). Also, the cost of inhibited chemicals is generally much higher than the non-inhibited chemicals (inhibitors typically add about $30-50 per ton to the cost of deicers). As transportation agencies spend millions of dollars each year on snow and ice control chemicals, there are growing concerns over the longevity of corrosion inhibitors in such chemicals and whether the inhibitors will work effectively in field environments subsequent to shed storage, sunlight exposure, and dilution. For carbohydrates, research is also needed to investigate whether they contribute to freezing point suppression and their potential effects on receiving bodies of water and pavements.

While there is uncertainty regarding how long the inhibitors remain effective during storage and on the road, the ability of deicers to reduce the freezing point of ice is still of primary importance. Thus, the ice-melting capacity, effective temperature range, corrosivity, and field performance of deicers need to be investigated to assist maintenance personnel make more informed decisions for snow and ice control.

[1] For simplicity, the term *deicer* will be used o refer to all chemicals for anti-icing, de-icing, and pre-wetting operations.

2. Objectives

The objectives of the proposed research are to evaluate the longevity of corrosion inhibitors in storage and on the road and their cost-effectiveness, and to establish a reliable measure to quantify the performance of anti-icing and deicing products.

Specifically, mostly through the combination of laboratory and field investigations, this Transportation Pooled-Fund study aims to answer the following important questions:

1) What is the longevity of the corrosion inhibitors, when in storage or on the road?
2) What is the duration the inhibitors remain with the deicers, when applied onto the road?
3) What are the effects of storage (temperature, UV intensity, exposure time, and type of deicer) on inhibitor longevity and effectiveness?
4) Do the inhibitors contribute to freezing point suppression or improve the effectiveness of deicers?
5) How does the laboratory test protocol correlate with deicer performance in the field?
6) What is the most effective product to use and its optimal application rate to combat ice formation, under each typical road weather scenario identified by the sponsor states?

By answering the first four questions, this research will allow the transportation agency to determine whether the inclusion of inhibitors into liquid or solid deicers is cost-effective, taking into account: the acceptable deicer corrosivity, reasonable duration of protection expected of inhibitors, and other agency-specific constraints.

The deicer products to be evaluated will be decided upon by the PNS and the Technical Advisory Committee. To promote the synergy between the research related to inhibitor longevity and deicer performance, it is suggested that these two parts or phases be conducted simultaneously.

As a starting point, the deicers that will be tested fall within the following PNS Categories (specific types will be determined by the TAC):

- PNS Category 1, Corrosion Inhibited Liquid - $MgCl_2$
- PNS Category 2, Corrosion Inhibited Liquid - $CaCl_2$
- PNS Category 4, Corrosion Inhibited Solid - NaCl

3. Background

3.1. Snow and Ice Control

In the northern U.S. and Canada, snow and ice control operations are essential to ensure the safety, mobility and productivity of winter highways, where the driving conditions are often worsened by the inclement weather. These maintenance activities offer direct benefits to the public such as fewer accidents, improved mobility and reduced travel costs. They also offer indirect benefits such as sustained economic productivity, reduction in accident claims and continued emergency services.

Depending on the road weather scenarios, resources available and local rules of practice, maintenance agencies use a combination of tools for winter road maintenance and engage in activities that include anti-icing, deicing, sanding and snowplowing. In recent years, transportation agencies across North America have been shifting from reactive strategies to proactive strategies for snow and ice control, such as anti-icing. Compared with traditional methods for snow and ice control (e.g., deicing and sanding), anti-icing leads to decreased applications of chemicals and abrasives, decreased maintenance costs, improved level of service, and lower accident rates (7). Reliable weather forecasts are key to a successful anti-icing program, as the pavement surface temperature dictates the timing for anti-icing applications and the appropriate application rate. When conducted properly, anti-icing can reduce the required plowing and decrease the quantity of chemicals required (8). In many conditions, anti-icing eliminates the need for abrasives, because it eliminates the cause of slipperiness (9).

Deicers applied onto highways often contain chlorides because of their cost-effectiveness. Acetate-based deicers (potassium acetate, sodium acetate, and calcium magnesium acetate [CMA]) have been used on some winter roadways as non-corrosive alternatives to chlorides. Electrochemical and weight loss tests of 14-17 month duration indicated that bridge structural metals, including steel, cast iron, aluminum, and galvanized steel corroded considerably less in CMA solutions than in NaCl solutions. Formates (sodium formate and potassium formate) and bio-based products have also emerged as potential alternative deicers. However, these non-conventional deicers have not been widely used, mainly due to concerns over their high cost or potential impact on concrete or toxicity to the aquatic resource.

The growing use of deicers has raised concerns about their effects on motor vehicles, transportation infrastructure, and the environment. Each year the U.S. and Canada uses approximately 15 million and 4-5 million tons of deicing salts, respectively (10). Motorists and trucking associations have become wary of deicers on their vehicles, as the vehicular corrosion (even though generally cosmetic) has been documented. On average, the deicer corrosion to each vehicle was estimated to cost $32 per year (11). In addition, chemicals may cause corrosion damage to the transportation infrastructure such as reinforced concrete structures and steel bridges (1). The cost of installing corrosion protection measures in new bridges and repairing old bridges in the Snowbelt states is estimated between $250 million and $650 million annually (12). Parking garages, pavements, roadside hardware, and non-highway objects near winter maintenance activities are also exposed to the corrosive effects of road salts. Indirect costs are estimated to be greater than ten times the cost of corrosion maintenance, repair and rehabilitation (13).

The total costs due to corrosion induced by winter maintenance practices have led to the addition of corrosion inhibitors to chloride-based deicers. The inhibitors are often organic and significantly increase the cost. The uncertainties of their longevity and performance need to be determined before decisions can be made regarding the cost-effectiveness of their use.

3.2. Performance Measures for Deicers

Roadway maintenance agencies strive to keep winter maintenance activities cost-effective and environment-friendly, while ensuring winter roadway safety, mobility, and productivity. These agencies need unbiased information regarding a number of key parameters in snow and ice control operations, such as: under various road and weather conditions, what type and amount of chemicals and/or abrasives need to be applied for achieving a safe driving surface condition, how long the chemicals/abrasives applied onto the roadway will be effective, etc.

In light of previous research, direct surface measurements (visual, pavement temperature, friction, etc.) may serve as a tool to address the aforementioned issues and thus improve roadway winter maintenance operations. Even though currently such measurements may not be a viable operational tool to be used by DOTs in winter maintenance, they can appropriately be used as an effective tool in a research environment.

NCHRP Project 6-14 (completed in 2002) suggested two scenarios that appear to be promising for operational trial by State DOTs. First, *qualitative* surface measurements or indices can be used to provide information to support winter maintenance decision-making. Second, surface measurements or indices and locations can be transmitted in near-real-time from the winter maintenance patrol or snowplow/spreader vehicles to a central office where the information is processed and transmitted to various users (14).

For the Pooled-Fund Members, the first scenario is more urgent and practical, as it has high potential for immediate implementation. Instead of assessing the roadway condition in *qualitative* terms, however, *quantitative* measurements would be more useful for enhancing the snow and ice control operations, through correlating affecting factors with roadway surface condition and evaluating the effectiveness of abrasives and/or chemicals applied onto the roadway under various conditions.

To predict deicer performance in the field environment, laboratory experiments of ice melting (SHPR H-205.1 and H-205.2), ice penetration (SHRP H-205.3 and H-205.4), and ice undercutting (SHRP H-205.5 and H-205.6) have to be conducted under given temperatures, as described in SHRP test methods (15). Such experiments are not only time-consuming and labor-intensive, but also difficult to generate reproducible results. Other drawbacks include the differences between actual and theoretical performance and, more importantly, the difficulty "to predict or design for the optimum combination of deicer and associated practices (15)."

Usually the theoretical melting capacities of a deicer product are characterized by its eutectic curve, or freezing point-concentration relationship. The *eutectic temperature* corresponds to the point at which the liquid phase borders directly on the solid phase; for a binary deicer-water phase diagram, this defines the lowest temperature at which a deicer can melt ice or snow. Figure 3-1 shows the eutectic curves of five chemical solutions (16). The eutectic temperature, however, does not provide reliable forecast of the effective temperature range of chemicals for snow and ice control.

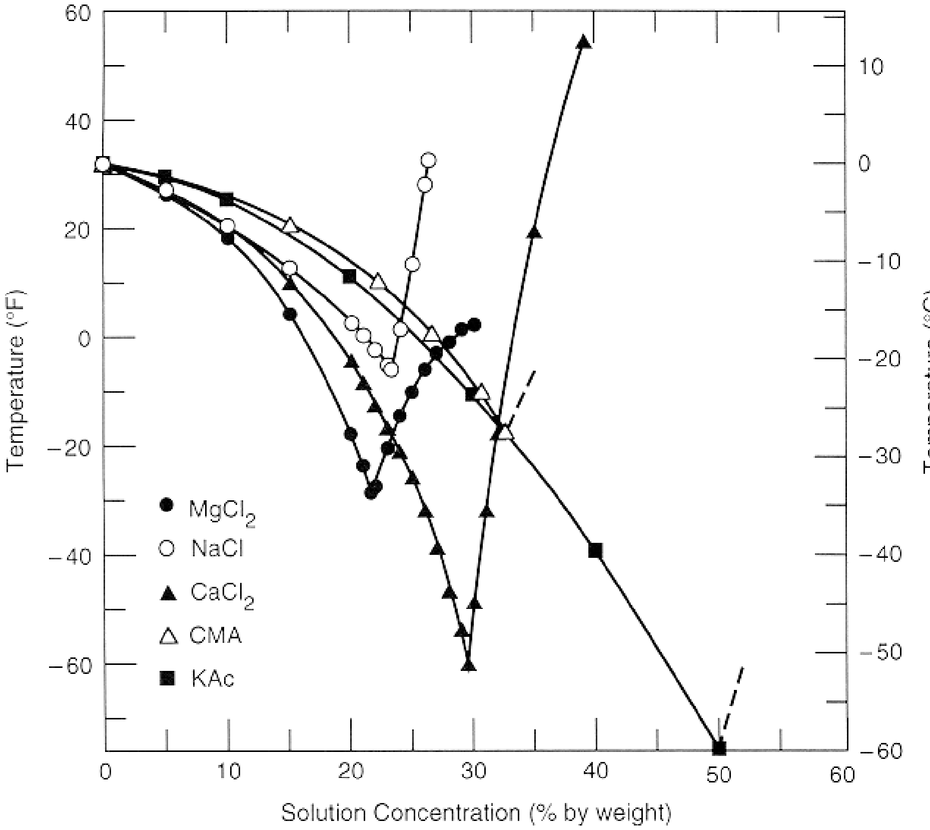

Figure 3-1: Eutectic curves of five chemical solutions (16)

Deicer products can be characterized by their physical, chemical and environmental attributes, time-dependent performance measures, as well as corrosivity to metals. A recent report by the Levelton Consultants summarizes the existing standard test methods for deicers, established by the PNS, the Strategic Highway Research Program (SHRP), American Society for Testing and Materials (ASTM), and American Association of State Highway and Transportation Officials (AASHTO) (4).

The PNS currently characterize various deicer products using a large number of tests for physical, chemical and environmental attributes of deicers, as listed in the 2006 Pacific Northwest Snowfighters Snow and Ice Control Chemical Products Specifications and Test Protocols (17):

1. Percent Concentration of Active Ingredient in the Liquid
2. Weight per Gallon
3. Corrosion Control Inhibitor Presence and Concentration
4. pH
5. Corrosion Rate
6. Percent Total Settleable Solids and Percent Solids Passing a 10 Sieve
7. Total Phosphorus
8. Total Cyanide
9. Total Arsenic, Barium, Cadmium, Chromium, Copper, Lead, Selenium and Zinc
10. Total Mercury

11. Milliequivalents or "meq"
12. Moisture Content of Solid Chemical Products.
13. Gradation
14. Visual Inspection and Field Observations.
15. Toxicity Test
16. Ammonia - Nitrogen
17. Total Kjeldalh Nitrogen
18. Nitrate and Nitrite as Nitrogen
19. Biological Oxygen Demand
20. Chemical Oxygen Demand
21. Frictional Analysis
22. Insoluble Material

The SHRP uses two major categories of physiochemical characterization tests to 1) determine material properties and 2) define deicing potential. The first category of tests consists of:

- “Principal chemical species identification and quantification.
- Minor chemical species identification and quantification. These potentially include additives and impurities.
- Moisture content including, if appropriate, water of hydration.
- Percent water insolubles.
- Identification of hazardous or toxic constituents.
- pH of aqueous solution. (15)”

The second category of SHRP tests consists of:

- “Freezing points and associated deicer concentrations in water.
- Eutectic temperatures and eutectic compositions.
- Solubility, chiefly at temperatures between 0°C and the eutectic temperature.
- Heats of solution in water.
- Viscosities of aqueous deicer solutions. (15)”

Both SHRP and PNS have test protocols for laboratory analyses of the corrosivity of deicers. The SHRP materials compatibility tests generally take advantage of ASTM test methods in quantifying the deicer effect on (or compatibility with) metals, nonmetals, concrete and pavement. The PNS test protocol for corrosivity is a modified version of the National Association of Corrosion Engineers (NACE) Standard TM1069-95. Levelton Consultants note many disadvantages of this test method, including a constant inhibitor concentration, lack of temperature and humidity control, and no direct correlation to field conditions (4).

Notably, the recent report by Levelton Consultants anticipated the trend towards “performance-based methodologies” in determining procedures and how this can accommodate technical advances in measurement science (4), such as using differential scanning calorimetry versus eutectic curves. The theory and application of differential scanning calorimetry is presented in the work plan below.

4. Work Plan

Task 0. Project Management

This task covers project management activities, aside from progress reporting activities detailed in Task 4. Dr. Xianming Shi at the Western Transportation Institute (WTI), Montana State University (MSU) will serve as the Principal Investigator to lead the multi-disciplinary research team as well as the primary contact for this project. Laura Fay, M.Sc. at WTI/MSU will serve as the co-Principal Investigator and lead Task 1 (Experiment Design and Planning) and Task 3 (Field Investigation). A Technical Advisory Committee (TAC) consisting of representatives from the PNS, contributing agencies, and invited participants will provide technical input/guidance throughout the duration of the research.

Scoping Meeting/Teleconference

At the outset of the project, the research team proposes having a teleconference with the TAC to review this work plan, receive suggestions, address concerns, and arrive at a consensus on the project scope of work. This meeting will also help determine how the research team should communicate with the TAC throughout the duration of the research. Responsibilities of the TAC members will be identified, and any issues with respect to the overall direction of the research effort will be addressed.

The work plan presented in this proposal will be revised based on feedback received at the scoping teleconference, and then re-submitted to the TAC for acceptance.

Ongoing Communications

Throughout the project duration, the research team will maintain good communication with the WSDOT Project Manager, the Steering Committee, and the TAC. The research team will work closely with WSDOT, the Steering Committee and the TAC to identify the corrosion inhibited chemicals to be evaluated and typical road weather scenarios to be simulated and to modify the project scope as necessary.

A consultant technical advisor with extensive field experience will be hired by WTI to work directly with the research team to provide ongoing assistance. The advisor will assure that the investigative approach is scientifically sound and will produce actionable results to assist state agencies in making proper business decisions on winter maintenance operations. In addition, the advisor will work as the liaison between the Steering Committee and the Principal Investigators and will be required to attend periodic technical meetings. The Steering Committee will provide necessary information to the TAC for review and the TAC will qualify the technical advisor prior to selection.

The WTI team proposes to keep the TAC apprised of project progress and issues that may require direction through quarterly progress reports and through teleconferences arranged with the liaison, the Steering Committee, and the TAC as necessary. To facilitate communications, the WTI Principal Investigators will correspond on a “day-to-day” basis with the technical advisor, or liaison, who will in turn communicate with the WSDOT Project Manager and the Steering Committee as necessary. To minimize cost and delay, all deliverables will be sent electronically for review and comments. The final report will be submitted in both hard copy and electronic formats. Throughout the duration of the project, WTI will submit progress reports and expenditure data to WSDOT on a quarterly basis, as detailed in Task 4.

Task 1. Experiment Design and Planning

This task covers planning activities for the two key components of this research, i.e., laboratory investigation and field investigation, which aim to address the project objectives, namely:

1) Determine the longevity of the corrosion inhibitors, when in storage or on the road.
2) Determine the duration the inhibitors remain with the deicers, when applied onto the road.
3) Determine the effect of storage on inhibitor longevity and effectiveness (i.e. how long the inhibitors are present and active while being stored at open and covered storage sites and how much their effectiveness diminishes due to exposure to the elements).
4) Determine whether the inhibitors contribute to freezing point suppression or improve the effectiveness of deicers.
5) Determine how the laboratory test protocol correlates with deicer performance in the field.
6) Determine the most effective product to use and its optimal application rate to combat ice formation, under each typical road weather scenario identified by the sponsor states.

Before proceeding with the field investigation, experiments under well-controlled laboratory conditions need to be carried out in order to: 1) establish rapid test methods essential to the success of the field investigation featuring massive sampling; 2) obtain a preliminary understanding of the factors affecting the longevity and performance of corrosion inhibitors; and 3) identify the best performing deicer products in terms of deicing performance and reduced corrosion. These preliminary results will help further define the scope for the field investigation.

As such, the laboratory investigation will establish appropriate means of quantifying the concentrations of chloride anion (and potentially the associated cations) and inhibitors and correlate such data to the deicer corrosivity data obtained with the PNS-modified NACE Standard TM0169-95 Test. The laboratory investigation will also establish a method to rapidly quantify deicer performance. In addition, laboratory experiments will be conducted in the MSU Civil Engineering Department Sub-zero Research Facility to study the effects of various factors on inhibitor longevity. This one-of-a-kind facility funded by the National Science Foundation and the Murdock Charitable Trust consists of state-of-the-art cold rooms with precise control of humidity, light and temperature (down to minus 80°F), to which the research team will have ready access.

Building on the knowledge gained from the laboratory investigation, the field experiments will be designed and conducted to validate or supplement the research findings in inhibitor longevity and deicer performance. The field investigation will also add credibility to the research findings and facilitate their implementation. To this end, a portable or permanent Road Weather Information System (RWIS) will be purchased (or rented) to accurately monitor road pavement and weather conditions. Storage sites, one covered (roof with three sides and the fourth side is open) and the other uncovered, will be built or acquired to test the deterioration of the solid products over time. Also, multiple storage tanks (agitated and non-agitated) will be used to test the deterioration of the liquid products over time. The Lewistown Cold Regions Test Bed and Research Facility will be rented to conduct the field operational tests.

While a highway could be used as the study site, the safety of travelers and researchers on the road during a winter storm is a disadvantage. Controlling the myriad of factors that potentially will influence the study results is also an issue on an active roadway subjected to natural weather events. Instead, WTI proposes the use of a research facility currently being designed in Lewistown, Montana (Figure 4-1). This cold region transportation research facility is being developed on an underutilized portion of the Lewistown airport to provide a safe and controlled environment for researchers that poses no disruption or risk to the traveling public. Development of this research facility is well underway and it will provide an excellent venue to investigate winter maintenance best practices. Construction is scheduled to occur during the fall of 2007 and summer of 2008. Planned infrastructure at the research facility includes asphalt pavement, a weather station, snowmakers, snowplow, friction testing equipment, and winter maintenance applicators for both liquid and solid products. The research facility will be fully operational for winter research during the 2008-2009 winter season.

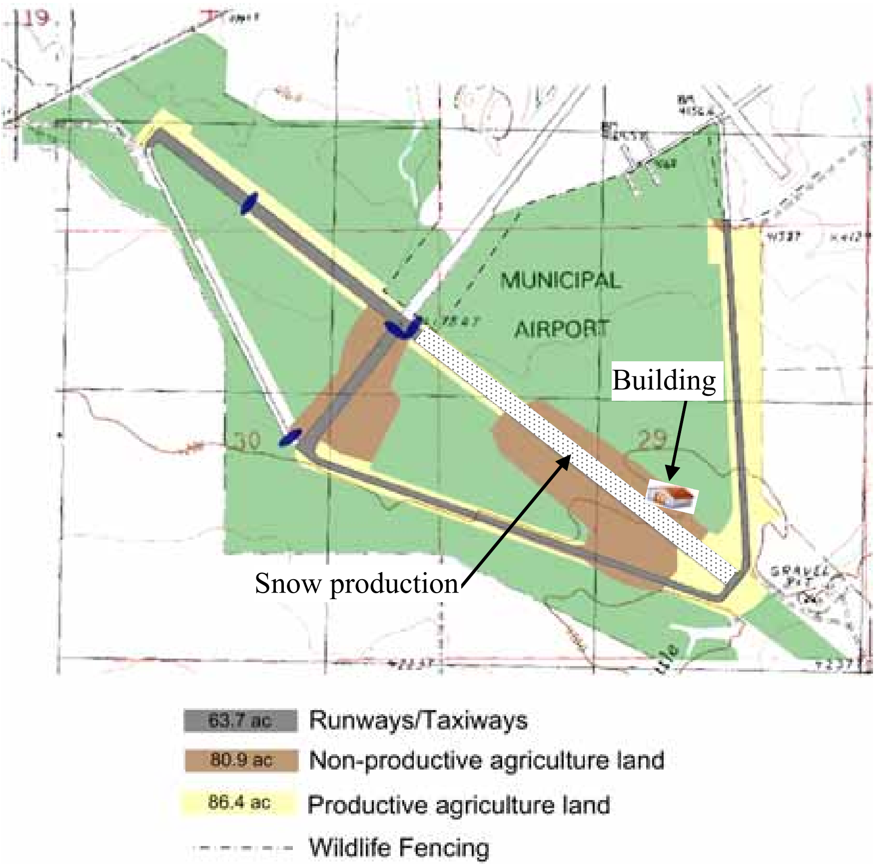

Figure 4-1: WTI test facility in Lewistown, Montana

The runways at this facility provide ample space for comparing each chemical during natural or artificial storm events. Forty-five hundred feet of two-lane asphalt pavement will be available as well as large sections for chemical storage. The snowmakers and climate will provide the opportunity to simulate storms or use natural events.

Temperature data from the Lewistown Municipal Airport can provide guidance in design of the experimental storms by generally defining the working parameters of the Lewistown Cold Regions Test Bed (Figure 4-2). Historical meteorological data such as precipitation type and quantity, humidity, dew point, wind speed and direction, and hours of day light will also be available.

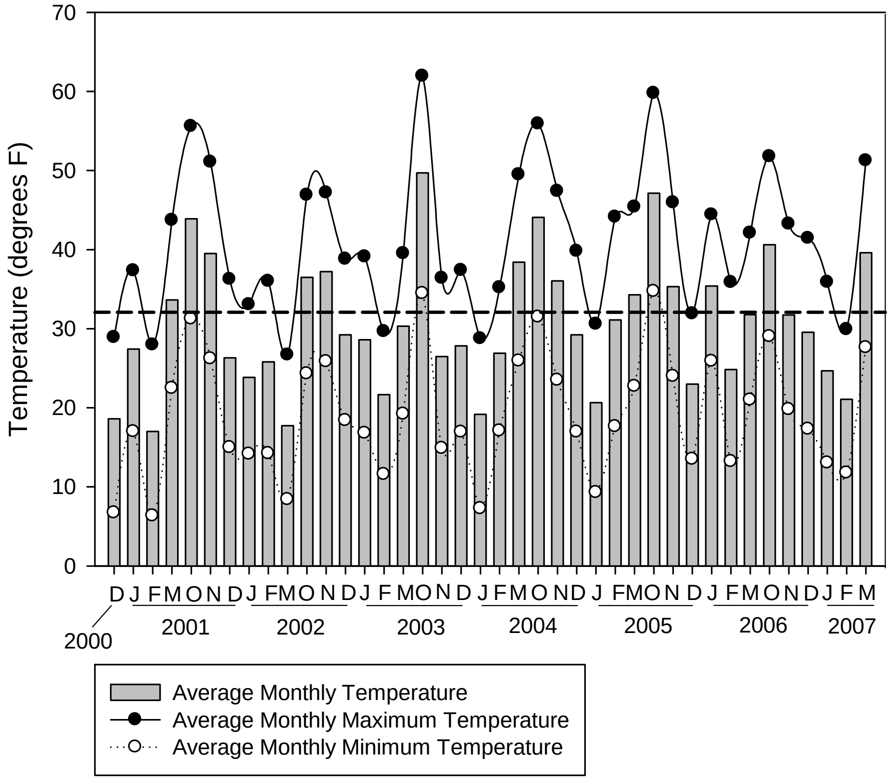

Figure 4-2: Average monthly temperature, minimum temperature, and maximum temperature from December 2000 to March 2007 collected at the Lewistown Municipal Airport. The dashed line is at 32 °F, D is December, J is January, F is February, M is March, O is October, and N is November

The uniqueness of the Lewistown Cold Regions Test Bed lends itself to performance comparisons of deicer when applied to a paved surface, in that such comparisons can be made side by side, simultaneously and in a controlled manner. The results can be measured, photographed and compared as performance differences occur. Different tests can be conducted as conditions change, such as temperature and depth or type of precipitation. The deicers and application rates can be controlled as field conditions are varied. Because this testing is in a field environment where temperature, humidity and wind speed and direction can only be measured and not controlled, duplication of test results would be difficult and therefore reporting must reflect this. For this reason the laboratory testing is important to provide complementary information to the field test findings.

Task 2. Laboratory Investigation

Task 2.1. Methods to Rapidly Quantify Chloride and Inhibitor Concentrations

This task involves establishing methods to rapidly quantify chloride and inhibitor concentrations. This would allow the research team to track the chloride and inhibitors in field samples once applied onto the roadway or to monitor the presence and concentration of the corrosion inhibitors subjected to various storage conditions.

In the field environment, both chloride and inhibitor in the deicer product may be diluted over time once applied on the roadway. As such, it is necessary to measure how much chloride remains on the pavement before trying to determine the presence and concentration of corrosion inhibitor. For instance, if the inhibitor has been significantly degraded by UV light or diluted to minimum concentration yet there is little residual chloride remaining on the roadway a few days after deicer application, the deicer corrosivity to metals may no longer be a valid concern.

One proven technology to quickly quantify the chloride concentration in deicer products is the silver/silver chloride (Ag/AgCl) electrode, which is often used for measuring electrochemical potential (*E*), either as a reference electrode or a chloride sensor. The electrode functions as a redox electrode and the reaction is between the silver metal (Ag) and its salt — silver chloride (AgCl):

$$Ag^0(s) + Cl^- \rightarrow AgCl(s) + e^-$$

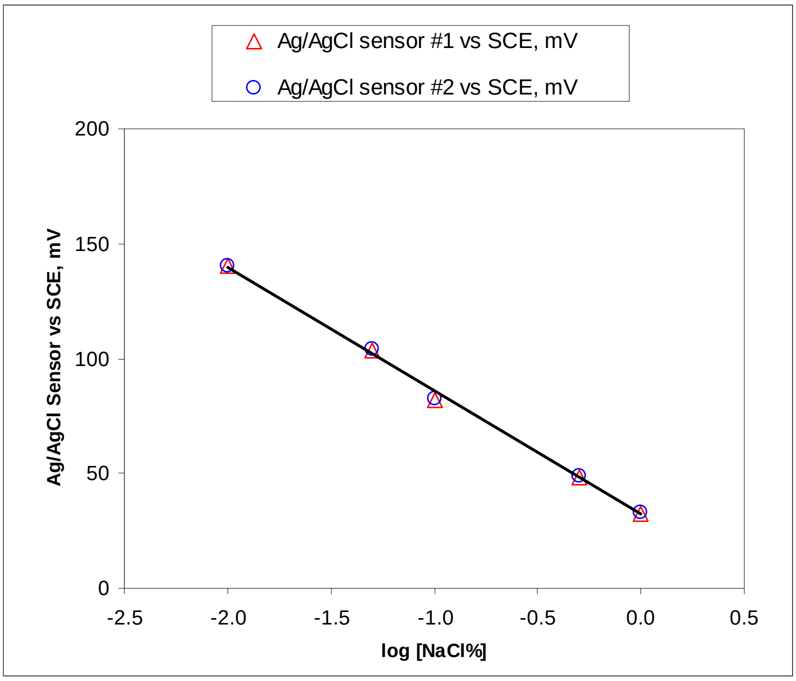

Figure 4-3: Calibration curve for chloride sensors, R^2=0.998

For each type of chloride-based deicer ($MgCl_2$, $CaCl_2$ and NaCl), the research team will prepare standard solutions with known chloride concentrations (using water as the solvent) and subject them to an Ag/AgCl electrode. The presence of the chloride will give a reading (*E*) proportional to the concentration. As such, a standard calibration curve can be established for each chloride. For any field samples with unknown chloride concentration, the electrode's response to the sample can be compared against the calibration curve to derive the chloride concentration. For example, Figure 4-3 shows a calibration curve for two chloride sensors prepared by the WTI Corrosion, Electrochemistry & Analysis Laboratory (CEAL) researchers. To validate this method, it may be necessary to directly test the chloride concentration of a few unknown samples using the chemical titration method for water-soluble chloride. Standard curves will be developed in winter 2007-2008 for each selected chloride based deicer.

If necessary, the concentration of the cations present in the deicers, e.g. calcium (Ca^{2+}), sodium (Na^{+}), and magnesium (Mg^{2+}), will also be tested using either ion-selective probes or ion chromatography. Ion chromatography, a form of liquid chromatography, is widely used to measure concentrations of major anions (e.g., chloride, fluoride, nitrate, nitrite, and sulphate) as well as major cations (e.g., sodium, ammonium, potassium, calcium, and magnesium) in the parts-per-billion (ppb) range. Concentrations of organic acids can also be measured through ion chromatography.

With the coordination of the PNS and TAC, the research team will sign confidentiality agreements with the vendors of selected PNS Category 1, 2 and 4 deicer products (corrosion-inhibited liquid $MgCl_2$, liquid $CaCl_2$ and solid NaCl). Knowing the chemical composition of the corrosion inhibitors and the method the vendor uses to detect the inhibitor will enable the research team to identify an appropriate technique to quickly quantify their concentration. To this end, one proven technology is the ultraviolet-visible spectroscopy or spectrophotometry (UV/ Vis), routinely used in the quantitative determination of solutions of transition metal ions and highly conjugated organic compounds. Organic compounds, especially those with a high degree of conjugation, also absorb light in the UV or visible regions of the electromagnetic spectrum. The research team will identify the *characteristic* UV-absorption peak for each of the selected corrosion inhibitors, possibly without knowing their exact chemical composition.

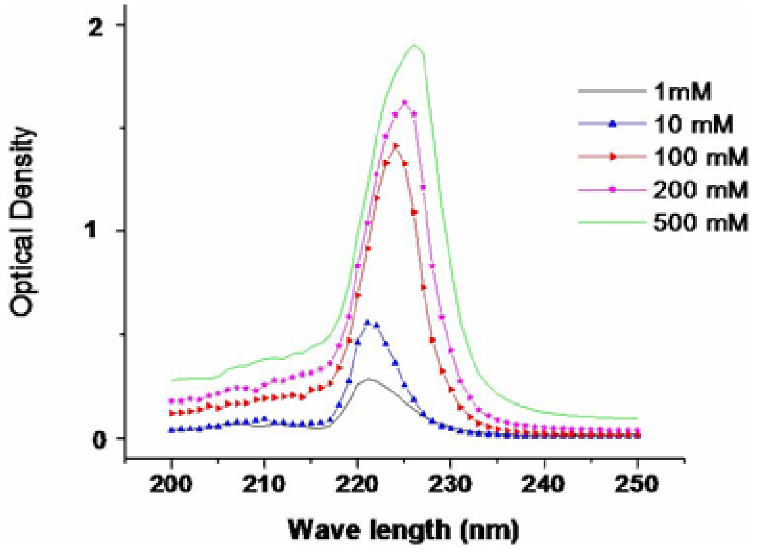

Figure 4-4: UV absorption spectra for standard samples of an organic inhibitor

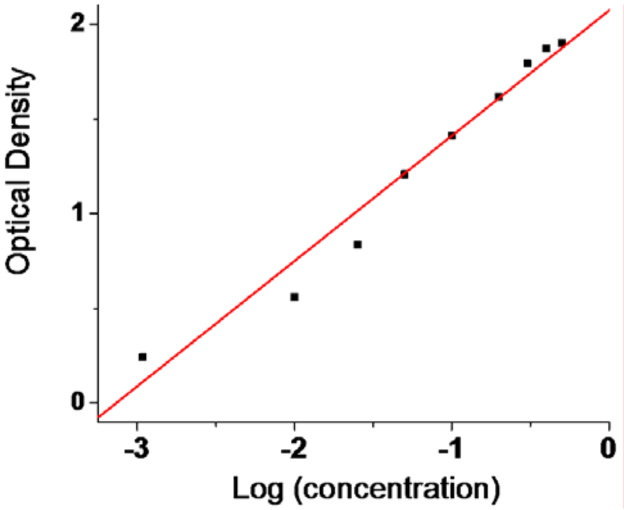

Figure 4-5: UV calibration curve for an organic inhibitor, R^2=0.98

For each corrosion inhibitor of interest, the research team will then prepare standard solutions with known inhibitor concentration (using water as the solvent) and subject them to a UV/Vis spectrophotometer. The presence of the inhibitor will give a response (e.g. optical density) proportional to the concentration. As such, a standard calibration curve can be established for each inhibitor. For any field samples with unknown inhibitor concentration, the instrument's response to the sample can be compared against the calibration curve to derive the inhibitor concentration. For example, Figure 4-4 and Figure 4-5 show UV absorption spectra for standard samples of an organic inhibitor and the corresponding calibration curve, respectively, obtained by the WTI CEAL researchers.

UV/Vis may be used as a means to rapidly detect the presence and concentration of corrosion inhibitors in deicer products and field samples, either in storage or on the pavement. To avoid background noise and interference, the UV spectrum of a sample without corrosion inhibitor will be tested as a control. If necessary, derivative UV/vis absorption spectrophotometry might be used in place of the conventional UV/Vis. Such technology presents the information content of a spectrum in a potentially more useful form, "offering a convenient solution to a number of analytical problems, such as resolution of multi-component systems, removal of sample turbidity, matrix background and enhancement of spectral details" (18). To validate the UV/Vis method, it may be necessary to directly test the inhibitor concentration of a few unknown samples with Gas-liquid chromatography (GLC), or gas chromatography (GC), a chemical analysis instrument for separating chemicals in a complex sample. Validating this method and establishing the calibration curves will occur during the winter 2007-2008.

Task 2.2. Method to Rapidly Quantify Corrosivity of Deicers

This task involves establishing a method to rapidly quantify corrosivity of deicers. To allow massive testing, a faster technique than the existing PNS/NACE corrosion test is desirable to evaluate the corrosivity of deicers.

The PNS/NACE test is based on a gravimetric method that entails cyclic immersion of multiple parallel coupons for 72 hours on a custom design machine. The weight loss result in MPY (milli-inch per year) is translated into a percentage, or percent corrosion rate (PCR), in terms of the solution corrosivity relative to a eutectic salt brine.

Electrochemical techniques may provide an attractive alternative to the gravimetric method in terms of allowing rapid determination of corrosion rate of metals and revealing information pertinent to the corrosion mechanism and kinetics. For instance, Figure 4-6 shows potentiodynamic polarization curves of a simulated deicer solution with or without corrosion inhibitors. Such polarization curves are expected to provide "signature" information pertinent to the corrosion behavior of steel in the inhibited or non-inhibited solution and to be used for quality assurance of deicer products.

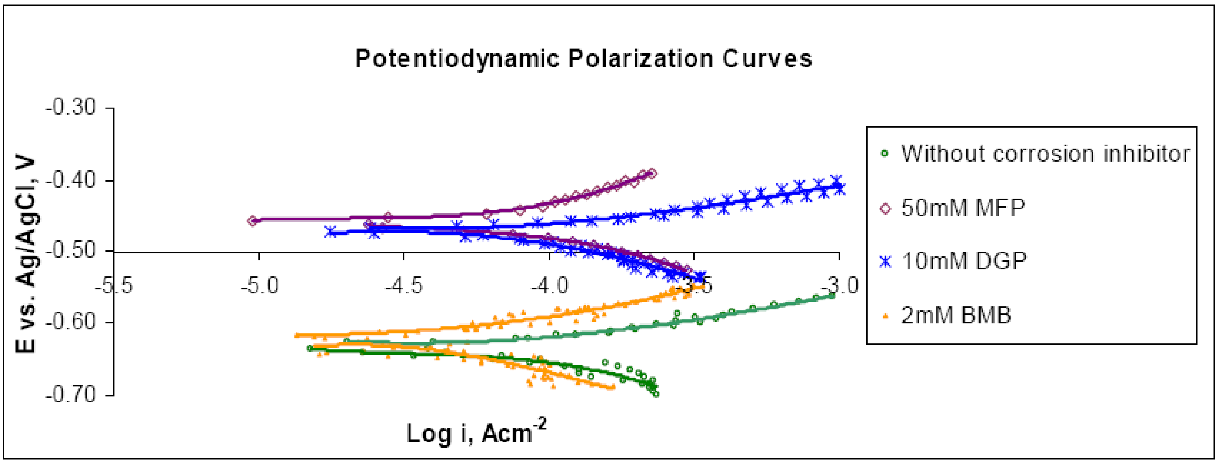

Figure 4-6: Potentiodynamic polarization curves of a steel sample in a simulated deicer solution, as a function of inhibitor presence

Shi and Song found that the corrosion potential (E_{corr}) and corrosion current density (i_{corr}) derived from potentiodynamic polarization curves were useful to predict the PCR value at reasonable accuracies (19). The electrochemical technique was able to rapidly (within hours) evaluate the corrosivity of deicer products in the presence and absence of corrosion inhibitors. Building on the preliminary success, the research team will implement the following improvements on the electrochemical test method:

1. Test multiple steel coupons in each deicer solution to ensure statistical reliability of corrosion test results;

2. Incorporate wet-dry cycles into the test duration to better simulate the cyclic immersion in PNS/NACE test and potentially to better simulate field conditions. Existing research has indicated that different moisture conditions were responsible for the discrepancies found in corrosivity pattern of deicers when various test protocols were employed (20).

With a few dozens tests, data from the improved electrochemical test method of corrosion to steel (E_{corr} and i_{corr}) are expected to correlate well with the PCR data. For each type of deicer, a standard curve (S1) can be established to correlate their corrosivity in PCR as a function of E_{corr} and i_{corr}. In addition, the research team will use the quick method to test the electrochemical behavior of steel in numerous deicer samples with known chloride and inhibitor concentrations (e.g., 5 deicer types × 4 chloride levels × 4 inhibitor levels). For each type of deicer, a second standard curve (S2) can be established to correlate its E_{corr} and i_{corr} as a function of chloride and inhibitor concentrations.

For any unknown chloride-based deicer product or field sample, its chloride and inhibitor concentrations can be quickly determined using methods described in Task 2.1, and its corrosivity in PCR can then be derived from the standard curves (S1) and (S2). To validate this method, it may be necessary to directly test the corrosivity of a few unknown samples with the PNS/NACE test protocol.

Preliminary testing in winter 2007-2008 of a larger list of potential deicers to be tested in the field will be conducted and the final short list of deicers to be used for field testing will be determined by the TAC using the available data.

Task 2.3. Method to Rapidly Quantify Deicer Performance

This task involves establishing a method to rapidly quantify deicer performance. The research team proposes to use differential scanning calorimetry (DSC) thermogram as shown in Figure 4-7(a), instead of eutectic curve, as the method to rapidly quantify deicer performance. DSC is an experimental technique that measures the energy necessary to maintain a near-zero temperature difference between the test substance and an inert reference material, with the two subjected to an identical (heating, cooling or constant) temperature program. By measuring the heat flow, DSC can detect phase transitions and quantify energy change, and measure kinetics of the transitions. DSC measurements typically require only a few milligrams of the sample, which is sealed in an aluminum capsule (21).

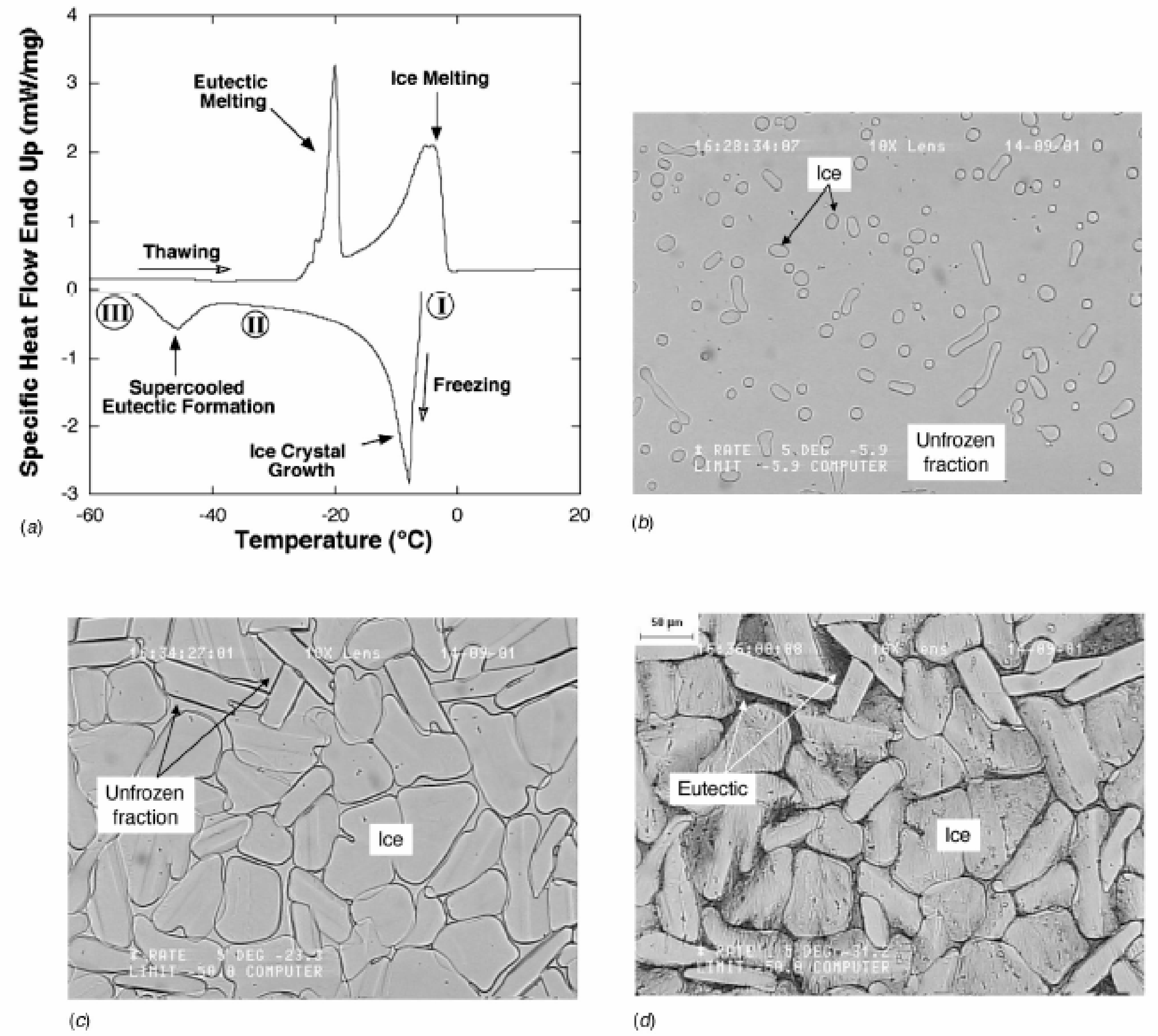

Figure 4-7: DSC thermogram and cryomicroscopy images during freezing/thawing of PBS (22).

Overall, the DSC thermogram provides useful information in regard to the thermodynamics of the deicer solution, which will provide insight into its freezing/thawing behavior in the absence of pavement. For instance, the freezing temperature near Point I (-9°C) in Figure 4-7 (a), is a much more reliable indicator of the start point of ice crystal growth than the eutectic temperature, and coincides with the *effective temperature* of using salt solutions for anti-icing or de-icing. Furthermore, the specific heat flow at the exothermic peak is a good indicator of *ice-melting capacity* of the chemical. As such, certified DSC curves can be used as a reliable quality assurance tool for deicer products.

Therefore, for each type of deicer, their DSC thermogram will be tested at a given heating/cooling rate for both inhibited and non-inhibited solutions, respectively, in order to determine if inhibitors contribute to freezing point suppression and if they provide any increase in the effectiveness of the deicers.

In addition, their DSC thermogram will be tested at the concentration suggested by the vendor or TAC as well as two lower concentrations that represent the field environments where different levels of dilution occurs as a function of accumulated precipitation, application rate of deicers, pavement temperature and so on. These results will shed light on what is the most effective product to use and its optimal application rate to combat ice formation, under each typical road weather scenario identified by the sponsor states. Such information is expected to help maintenance personnel make more informed decisions regarding the type and amount of deicers to apply under various road weather scenarios.

These laboratory results will be correlated with field results, wherever possible, as described in Task 3. If there is a strong correlation between the two groups of results, it can be concluded that the laboratory test protocol based on DSC is a reliable tool for quantifying deicer performance. Furthermore, such a test protocol is expected to be used for quality assurance of deicer products as well, by both the deicer vendors and the deicer users (mainly transportation agencies).

Task 2.4. Inhibitor Longevity under Laboratory Conditions

Field investigations for inhibitor longevity, both in storage and on the road, will be conducted as much as is practicable. Many of the parameters in the field, however, can only be documented rather than controlled. It is nearly impossible to reproduce the field results, or to conduct field tests of different products in similar environmental conditions. As such, it is important to investigate in the laboratory setting the effect of parameters such as dilution, temperature, UV intensity and duration on inhibitor longevity and performance. The research team is convinced that a viable link between inhibitor concentration and PCR data from the PNS/NACE corrosion tests can be made to the TAC's satisfaction. This link is critical to ensuring historical PNS corrosion testing and product qualification remains viable while allowing for test result duplication and national recognition of this research effort and testing procedure. This procedure, and link to field conditions, may become a PNS standard test procedure if a longevity threshold is established.

To help explain the results from the field investigation where many parameters fluctuate over the time of investigation, experiments will be conducted in the MSU Civil Engineering Department Sub-zero Research Facility to research how dilution, UV intensity and duration, temperature, and exposure time affect the longevity and performance of corrosion inhibitors. The methods described in Task 2.1 will be utilized to quantify the inhibitor concentration and standard degradation curves will be established for corrosion inhibitor in each type of deicer during the winter 2007-2008.

As illustrated in Figure 4-8, there are many factors in the field environment that could potentially affect the inhibitor longevity and performance. Due to time and budget constraints, this project will only research the factors highlighted in light blue in the diagram. Other factors will be documented in this research, and they can also be investigated if suggested by the Steering Committee or the TAC and deemed feasible within the resources available for the study.

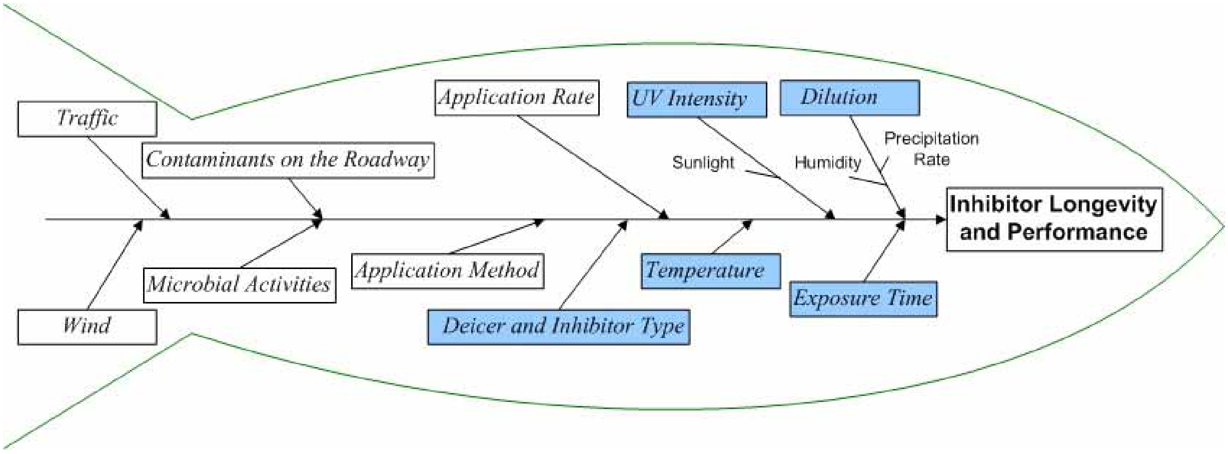

Figure 4-8: Fish diagram illustrating the influential factors in inhibitor longevity and performance

The tasks highlighted in Figure 4-8 will be tested in the laboratory at the MSU Civil Engineering Department Sub-zero Research Facility in 2007-2008. For each combination of deicer and inhibitor, the environmental parameters- UV intensity, dilution, temperature and exposure time - will be simulated to establish an inhibitor degradation curve in a well controlled environment, so that it may be applied in the field in 2008-2009 at the Lewistown Cold Regions Test Bed.

To accomplish this, the deicers and inhibitors selected by the Steering Committee and approved by the TAC will be applied at varying concentrations and methods of sample recovery will be determined. UV intensity will be varied for each replicate of samples, as well as temperature and exposure time. The final product will be a table showing how the selected deicers and inhibitors are impacted by dilution, temperature, exposure time and UV intensity. To statistically validate this process each modified variable will be tested in triplicate, therefore 81 samples will be run to validate a single deicer and inhibitor.

Task 3. Field Investigation

Preliminary testing and development of rapid test methods for processing the quantity of samples to be collected in the field and development of a general understanding of the factors that affect inhibitor longevity, field testing and sampling will be investigated. Initial testing of previously developed methodologies and those developed specifically for this project in terms of inhibitor longevity, inhibitor corrosion protection and the necessary concentration of inhibitor, and application of deicers in the field will be conducted during the winter of 2007-2008 at WTI-MSU, the Lewistown Cold Regions Test Bed and the in the MSU Civil Engineering Department Sub-zero Research Facility.

Field experiments will be conducted under realistic and typical road weather conditions. Field data, in conjunction with laboratory data, will ensure that the research results are applicable to actual situations governing the storage and use of corrosion inhibited deicers. Research sponsored by DOTs has usually raised concern with regard to the usability of laboratory test results mimicking or reflecting real conditions seen on highways. Field application research is needed by DOTs if changes in methods or specifications are to be made.

Task 3.1. Inhibitor Longevity: Storage Monitoring

The longevity of solid and liquid corrosion inhibited deicers during storage will be addressed by measuring the inhibitor concentration over time in realistic storage containers. For solid chemicals, both covered and uncovered storage facilities will be built on site as part of the Lewistown Cold Regions Test Bed and Research Facility. Deicer will be stored using two methods: in two 25-30 ton piles outside with full exposure to the elements and two 25-30 ton piles within an enclosure consisting of three walls and a roof. The solid deicer piles will be placed on concrete pads approximately 25 x 30 ft. The covered concrete pad will be flat and the uncovered concrete pad will slope in two directions so that leachate from each pile can be collected in cistern tanks for monthly testing. The structures will be designed to reflect current DOT facilities and will be approved by the Steering Committee and TAC. The facilities to hold the solid deicer will be built at the Lewistown Cold Regions Test Bed.

The sampling method for the solid deicers collected from the storage enclosure and piles will follow the ASTM D632 standard (www.astm.org). The method requires no less than three samples be selected at random from the different storage configurations. Each sample is obtained by scraping aside the top layer of material to a depth of at least one inch and taking an approximate one pound sample to a depth of at least six inches. Sampling can be done to ensure a representative cross-section of the material, where collected sample is thoroughly mixed to make up one composite sample representative of the lot. A second way to sample would be to collect multiple samples at varying depths to look for concentration differences. This can be achieved using a soil sampling probe. The sample is then pulverized so that it passes through a 300-µm (No. 50) sieve. The pulverized solid deicer is then diluted with nitric acid and distilled water, and mixed. Calcium carbonate ($CaCO_3$) is added to neutralize the solution to pH ~ 7, and potassium chromate (K_2CrO_4) solution is added as an indicator. The sample is then titrated with silver nitrate ($AgNO_3$) solution until a change in color occurs - a persistent yellowish brown endpoint comparable to a standard. For this research, to allow massive sampling, the chloride concentration will be measured using a calibrated Ag/AgCl electrode instead of titration, as discussed in Task 2.1. The inhibitor concentration will be measured using the identified UV/Vis signature for each inhibitor (prior to addition of potassium chromate and titration, if any).

The liquid deicers will be stored in 3000 gallon poly tanks (Norwesco®), three tanks will be agitated once a week for one hour and three will not be agitated. The tanks will be stored outside on level gravel. Samples will be collected daily for the first week, weekly for the first month and bi-monthly there after using a Van Dorn Bottle®. Three samples will be collected each time at varying depths to look for stratification with in the tanks. Prior to each sample collection the Van Dorn Bottle® will be cleaned to prevent cross contamination. The collected deicer will then be tested for chloride, cation, and inhibitor concentrations following the methods discussed in Task 2.1.

Testing will begin winter 2007-2008, and an inhibitor degradation curve could be established within the first year. Sampling intervals may change based on the data. The 1-year time frame would also reflect the longest amount of time a DOT may retain a deicer and therefore be a realistic testing time frame. An initial base line sample of solid and liquid deicers will be collected and tested for chloride, cation, and inhibitor concentrations. Upon delivery of solid and liquid deicers, samples will collected and sent to the Idaho DOT for quality assurance testing before the experiment will begin. Meteorological parameters such as air temperature, relative humidity, timing of sunrise and sunset, and UV intensity will be measured throughout the experiment, using a weather station, RWIS, and in-situ probes. Standard degradation curves established in Task 2.4 will be used to interpret the field test results related to inhibitor longevity and effectiveness.

Results from the first year of inhibitor longevity testing should provide sufficient knowledge so that the Steering Committee and TAC may select the solid and liquid products of interest for further testing in Task 3.2.

Task 3.2. Inhibitor Longevity and Deicer Performance: Field Operational Tests

As discussed in Task 1, the Lewistown transportation research facility is the recommended site for field operational tests, the purposes of which are to test the inhibitor longevity once applied onto the roadway and to test the deicer performance under different road weather scenarios. Three artificial storm events will be simulated at the test bed in order to generate reproducible results for the field investigation. It is also possible to conduct the field operational tests in one natural winter storm event, in consultation with the Steering Committee and the TAC.

For selected road weather scenarios to be simulated by artificial storm events, appropriate deicer products and application rates will be determined through a questionnaire posted on the Snow and Ice list serve to survey the state of the practice and utilize the insight based on field experience of winter maintenance professionals or by rates recommended by the Steering Committee and the TAC. Results from this survey will be provided to the Steering Committee and the TAC for the final decision on deicer products and application rates to be tested in each road weather scenario. The selection of application rates will also consider the existing FHWA Anti-icing Guidelines (16), and preliminary findings from a pending WTI/Caltrans research project (start date Nov. 2007) with a focus on optimizing application rate of deicers for various road weather scenarios. Field testing may also reflect the application rates used for re-application during storm events and will be determined in consultation with the Steering Committee and the TAC. Additional testing may be done mixing varying combinations of solid and liquid products with or without corrosion inhibitors. Such variations will be determined in consultation with the TAC and take into account the economic feasibility of the field investigation.

The focus of this research is corrosion-inhibited liquid $MgCl_2$, liquid $CaCl_2$ and solid NaCl (PNS Categories 1, 2, and 4, respectively, and potentially corrosion-inhibited liquid NaCl) and each product will be applied at an application rate selected by the Steering Committee and the TAC for the specific road weather scenario.

Some field trials will be conducted in the winter of 2007-2008 to test the validity of methods for field application of deicers and sampling of deicer residues on pavement. Equipment to be used for application of deicers may be scaled down from a snow plow to a 4-wheeler (quad) with liquid and solid application abilities. The application methods will be consistent but scaled down such that liquid deicer stream application or solid deicers dispersal and application rate mimic actual DOT practices. For example a typical anti-icing application rate for a liquid deicer of 40 gallons per lane-mile is equivalent to 0.5 ounces per square yard for the 400 ft test section ~266 ounces would be needed to reflect this application rate. In addition, methods to sample deicer residues from pavements (with frost, black-ice, snowy, icy conditions) will also be experimented in the winter of 2007-2008 before the full-scale testing in the following winter.

Laboratory testing in the 2007-2008 will include using the MSU Civil Engineering Department Sub-zero Research Facility. The dilution factor of the deicers and inhibitors will tested as well as the potential percent recovery of material off asphalt pavement surfaces. This testing will utilize asphalt pavement slabs made by the MDT.

At least three field trials will be conducted in the winter of 2008 – 2009, and each will simulate a different road weather scenario. Testing will be performed on an unoccupied paved surface capable of handling multiple test sections at once and will be equipped with the RWIS. Traffic will not be taken into consideration at this time in order to minimize the number of variables. The road surface will be cleaned between tests to avoid contamination from residue of previous tests.

As shown in Figure 4-8, the test section will be split into 400 ft sections A through E to accommodate application of the following: corrosion-inhibited liquid $MgCl_2$-based, liquid $CaCl_2$-based, liquid NaCl-based, and solid NaCl-based deicers. A 400 feet buffer zone between each test section will be used to flush or switch the applicator and clean the application vehicle to prevent cross contamination of deicers, and there will also be a control section on which no deicer is applied.

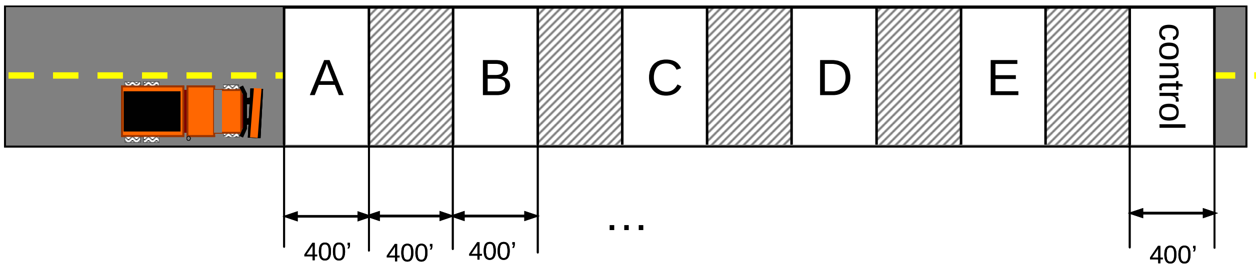

Figure 4-9: Layout of test sections and buffer zones

Conditions on each section (A-E and Control) will be continuously monitored and randomly spatially sampled throughout three artificial storms to a sufficient extent that statistical inferences can be made from the data. Each section will be divided into 40 squares, of which eight will be sampled based on a randomized block design for the liquid deicers and 16 for the solid deicers to accommodate the difference in application. The selected test squares will be determined by a random number generator, such that each of the 40 squares has an equal likelihood of being selected. The samples will be used to represent the variations in chloride and inhibitor concentrations as well as pavement condition due to the non-uniform distribution of deicers (resulting from the forward motion of the deicer application vehicle), the traffic effect on wheel paths, the application method of particularly liquid deicers, inherent variations in initial pavement condition, and other factors.

Each of the sample squares will have a digital picture taken to indicate the apparent pavement condition, pavement friction coefficient measured to indicate deicer performance using a hand held tribo-meter, and when available, slush sample (salt/snow mixture) collected to test chloride and inhibitor concentrations. For storms where slush samples will not available artificial surfaces (e.g. Teflon, membrane, Petri dish) will be used to collect samples. The sampling rate will be determined in consultation with the TAC with collection occurring at least twice during each artificial storm event. Statistical analysis will be conducted using ANOVA variance tests and there will be pictures presented in time series.

Meteorological data collected will include ambient air temperature, precipitation type and amount, water content of the precipitation (snow pack), light intensity including UV spectral intensity, duration of sunlight, relative humidity, and wind speed and direction. The RWIS station will be used to measure pavement temperature.

The field test results are expected to answer the following questions:

- What is the longevity of the corrosion inhibitors, when on the road?
- What is the duration the inhibitors remain with the deicers, when applied onto the road?
- How does the laboratory test protocol correlate with deicer performance in the field?
- What is the most effective product to use to combat ice formation, under each typical road weather scenario identified by the sponsor states?

Task 4. Project Reporting

As one activity under this task, the research team will provide quarterly progress reports to the TAC through the WSDOT project manager. These progress reports will cover recent activities associated with Tasks 1 through 3. The summary will describe, for each task, activities completed in the most recent three-month period, activities foreseen for the next three-month period, and the estimated percentage of work complete. The progress reports will also include a brief, executive summary-level narrative of preliminary findings.

As necessary, the progress reports will describe any issues or obstacles that have affected project progress or the direction of the research. However, the research team believes that it is better to address these issues as they arise; therefore, regular communication between the team and the TAC (described under Task 0) will be used to more quickly resolve any such issues.

The research team will submit the progress reports electronically as Microsoft Word™ documents. If the TAC members are interested, the research team may present the progress report as a Microsoft PowerPoint™ presentation in a teleconference that would be arranged by the TAC.

A few months before the completion of this research, a draft final report will be prepared in conformance with any WSDOT template standards and submitted electronically to the TAC for review. The reviewers' comments will be incorporated wherever possible, and the final report will be then submitted in both hard copy and electronic formats to the TAC at the conclusion of the project. Pending approval of the project committee, the final report will include the following main sections:

- Executive summary
- Introduction
- Methodology
- Results and Discussion
- Conclusions and Recommendations (including future research needs)

The budget for this task also includes funding for the Principal Investigator to travel to one to-be-determined conference (e.g., TRB Annual Meeting in Washington, D.C.) to give a presentation on the results of this research.

5. Products

The main deliverable will be the final report that documents the background, methodology, and research findings of this project. Other deliverables will include the quarterly progress reports submitted to the Department throughout the project duration.

6. Implementation

The consultant technical advisor will work with the research team to assure that the investigative approach is scientifically sound and will produce actionable results to assist state agencies in making proper business decisions on winter maintenance operations. In addition, the advisor will work as the liaison between the Principal Investigators and the TAC as well as other stakeholder groups such as Clear Roads Program and Aurora to facilitate the implementation of research findings.

Due to the complexities associated with competing priorities for winter maintenance operations, such as safety, environmental stewardship, and budget constraints in combination with an infinite number of possibilities for road weather scenarios, including precipitation type and severity, temperature, road type and condition, and deicer (and inhibitor) type and concentration, it is not feasible to recommend the exact combination of deicer and inhibitor for all winter scenarios. The individuality of states representing the PNS and other contributing agencies also limits the implementation of a recommended product. However, the research results will benefit states by providing significant information on which to base their selection of deicers and inhibitors. For instance, the proposed research is designed to answer the very important questions related to longevity and cost-effectiveness of corrosion inhibitors. This research will provide the information DOTs need in deciding whether or not to use corrosion inhibited products, how they should be stored, and how long they will remain effective in storage. The investigation of deicer performance will also provide documented laboratory and field findings that will assist maintenance personnel in the selection and usage of deicers.

In addition, the research results may provide the impetus for developing two new test methods to be adopted by the PNS and others. Depending on the outcome of the research, a test method for longevity of corrosion inhibitors may be deemed necessary due to the continuing advances and development of new inhibitors. This research may identify the important parameters to be included in the inhibitor longevity test protocol, such as humidity, temperature, UV intensity and duration, and dilution, as well as identify which parameters can be excluded. A second possible test method whose development could be initiated by the results of this research is one that quantifies deicer potential or performance, based on the differential scanning calorimetry.

This research is expected to significantly advance the knowledge base for winter maintenance best practices, and thus help maintenance agencies address the challenge in meeting multiple priorities in safety, mobility, environmental stewardship, and infrastructure preservation in a fiscally responsible manner. By allowing more informed decisions for snow and ice control strategies and tactics, it is expected to help improve the level of service, reduce the winter maintenance costs, and reduce the corrosion and environmental impacts due to snow and ice control operations. Given the improved understanding of inhibitor longevity and deicer performance and the established rapid tests for these properties, this research is expected to help the deicer manufactures and vendors come up with better practices in product design, quality control/quality assurance, storage and transport and become more competitive in the market in meeting the user needs.

7. Work Time Schedule

Table 7-1 is a high-level schedule for the project, where the duration of each task is given in months. The schedule has been established for a three-year period, assuming a start date of October 1, 2007.

Table 7-1: Proposed project timeline by month

		Calendar Year / Month																																			
		2007			2008												2009												2010								
Tasks	*Milestones*	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Task 0. Project Management																																					
Project kickoff	*Oct-07*																																				
Task 1. Experiment Design and Planning																																					
Task 2. Laboratory Investigation																																					
Task 2.1. Methods to Rapidly Quantify Chloride and Inhibitor Concentrations																																					
Task 2.2. Method to Rapidly Quantify Corrosivity of Deicers																																					
Task 2.3. Method to Rapidly Quantify Deicer Performance																																					
Task 2.4. Inhibitor Longevity under Laboratory Conditions																																					
Task 3. Field Investigation																																					
Task 3.1. Inhibitor Longevity: Storage Monitoring and Cost-Benefit Analysis																																					
Task 3.2. Deicer Performance: Field Application																																					
Task 4. Project Reporting																																					
Quarterly progress reports	*End of each quarter*																																				
Draft final report	*Jul-10*																																				
Final report w/ executive summary	*Sep-10*																																				

8. Budget and Level of Effort

The estimated budget and detailed efforts are listed in Table 8-1, totaling \$514,000 and 6,780 person-hours, respectively. The Transportation Pooled Fund will provide 70.8% of the funding (\$364,000) and the Western Transportation Institute will provide 29.2% of the funding (\$150,000) over the three federal fiscal years. The personnel will include Dr. Shi (PI), Ms. Fay (Co-PI), a Senior Field Engineer (as Liaison with the RAC), Dr. Nguyen (Electrochemist), Ms. Huang (Statistician), Ms. Akin (Coordinator with Lewistown Test-bed Project), Mr. Cuelho, a Civil Engineer, WTI administrative support, laboratory technician, and undergraduate students. Other items include: Travel (between Bozeman and the Lewistown Test-bed; trips to report progress and present results); Operations/Communications; Contracted Testing Services (for UV-Vis, DSC, and other chemical analysis); Lewistown Facility Usage (for the use of portable road weather sensors, test tracks, storage sites and tanks, and office space); and Corrosion Lab Testing and Other Supplies (for PNS/NACE tests, electrochemical tests, ice-melting tests, etc.). Indirect costs are charged at 42.5 percent of direct costs; this rate is the standard used by Montana State University on research contracts.

Estimated costs to run a 3-day field experiment (an experimental/created or natural storm) at the Lewistown Facility is ~\$20,000 (~\$6,700 per day). This includes the cost of all facilities, equipment (snow making, lights, electricity, water), and on-site employees as well as the cost to conduct the experiment from beginning to end. This does not include processing of samples in the laboratory.

Table 8-1: Proposed project budget by cost category

	Role	Federal Fiscal Year			Hours	Cost
		2007	2008	2009		
Dr. Xianming Shi	PI	168	200	200	**568**	**$33,127**
Ms. Laura Fay	Co-PI	168	336	336	**840**	**$31,380**
Dan Williams	Liasion/ Advisor	100	200	100	**400**	**$18,832**
Laboratory technician	Chemist	590	140	28	**758**	**$21,161**
Dr. Tuan Anh Nguyen	Chemist	504	140	28	**672**	**$20,368**
Ms. Jiang Huang	Statistician	40	80	40	**160**	**$5,070**
Ms. Michelle Akin	Coordntr w/ Lewistown	40	200	80	**320**	**$10,796**
Eli Cuelho	PE/ Research	12	12	12	**36**	**$1,824**
A Civil Engineer	Research	0	70	0	**70**	**$3,349**
Undergraduate Student	Research	400	1,600	800	**2,800**	**$30,800**
Business Manager	Support	12	12	12	**36**	**$1,532**
Administrative Support	Support	40	40	40	**120**	**$3,017**
Labor (hours)		**2,074**	**3,030**	**1,676**	**6,780**	
Labor ($)		**$61,822**	**$74,292**	**$45,598**		**$181,712**
Travel		**$2,000**	**$4,500**	**$2,400**		**$8,900**
Operations/Communications		**$400**	**$1,490**	**$700**		**$2,590**
Infrastructure start-up cost		**$80,000**				**$80,000**
Contracted Testing Services		**$3,500**	**$4,500**	**$2,500**		**$10,500**
Lewistown Facility Usage		**$3,000**	**$44,000**	**$18,000**		**$65,000**
Corrosion Lab Testing and Other Supplies		**$7,000**	**$2,500**	**$2,500**		**$12,000**
Indirect (42.5%)		**$67,032**	**$55,795**	**$30,472**		**$153,298**
Total Cost ($)		**$224,754**	**$187,076**	**$102,169**		**$514,000**

Transportation Pooled Fund	70.8%	**$364,000**
Western Transportation Institute	29.2%	**$150,000**

Table 8-2: Breakdown of 2007-2008 infrastructure start-up cost

Infrastructure	**Quantity**	**Cost**	**Who is covering the cost?**
Poly tanks	6	$18,500	PNS
Concrete Pads	2	$25,000	WTI-Lewistown
Building	1	$11,000	PNS
RWIS	1	$13,200	WTI-Lewistown
Deicers			PNS
Ice Slicer Elite	50 tons	*	
GLT	300 gallons	*	
Freezegard Zero CI Plus	6000 gallons	$4,200	
Salt Brine	6000 gallons	*	
Geomelt C	6000 gallons	$207 ton	
sand/aggregate	50 tons	*	
salt (for salt/sand)	5 tons	*	
Total estimated cost for PNS:		$33,700 + remaining deicers not yet quoted	
Total estimated costs for WTI:		$38,200	

* Price quote not yet available.

9. Researcher Qualifications

The research team has the right combination of multi-disciplinary expertise needed to address this proposed research related to inhibitor longevity and deicer performance, including work in the key areas of corrosion science, chemistry, electrochemistry, cost-benefit analysis, stakeholder outreach, applied statistics, road weather information systems, field investigation, and winter maintenance best practices.

WTI Overview

The Western Transportation Institute (WTI) is the nation's largest transportation institute focusing on rural transportation issues and is designated as a National University Transportation Center sponsored by the U.S. Department of Transportation. The Institute was established in 1994 by the Montana and California Departments of Transportation, in cooperation with Montana State University. A primary focus for WTI has been *Winter Maintenance and Effects*, the vision of which is to research and mitigate corrosion and winter effects on transportation systems, through innovation and multi-disciplinary partnerships. As described earlier, WTI has the combination of facilities, experienced personnel, and funding resources necessary to successfully complete this important project.

Qualifications of Research Team Members

Resumes for key project staff (except the consultant technical advisor) are included in Section 10.

Xianming Shi, Ph.D., Winter Maintenance and Effects Program Manager at WTI, will serve as principal investigator and primary contact for this project. He will be responsible for managing the project, ensuring that the objectives of the study are accomplished, implementing the project's tasks and preparing the final report. Dr. Shi has unique experience and expertise for transportation research, with a multi-disciplinary background and diverse skills in corrosion science, chemistry, electrochemistry, and winter maintenance research. He has strong capabilities and more than 12 years of experience in conducting engineering and science research, with demonstrated publications records and extensive project experience. Dr. Shi has a clear understanding of the state of the practice and important issues pertinent to winter highway maintenance activities. He is an active member of four Transportation Research Board (TRB) Committees ranging from corrosion, concrete science, polymer concretes, to winter maintenance, under the U.S. National Academies. He is an active member of the National Association of Corrosion Engineers (NACE) International and the Materials Research Society (MRS), and a past member of the American Chemical Society (ACS). He is also an Associate Research Professor at the Civil Engineering Department, Montana State University –Bozeman, and a Specially Invited Professor at the School of Materials Science & Engineering at Tianjin University, China. At WTI, much of his research has focused on weather and winter mobility issues, and he is actively involved in activities of the PNS. He also leads the WTI Corrosion, Electrochemistry & Analysis Laboratory (CEAL), which was funded by the U.S. Research and Innovative Technology Administration. Dr. Shi holds his Ph.D. in Chemistry from Institute of Chemistry, Chinese Academy of Sciences and a second M.Sc. in Industrial & Management Engineering from Montana State University - Bozeman.

Laura Fay, M.Sc., a Research Scientist at WTI specializing in environmental science and earth sciences, will serve as co-principal investigator and lead the planning and field investigation tasks. She has five years of laboratory and field research experience, during which she developed skills in numerous types of field studies, including stream inventory studies, fish surveys, stream-bank stability studies, and road decommissioning studies. She also has experience facilitating partnerships among public and private agencies, Native American tribes, and the general public on a variety of environmental issues. Her current research focus at WTI includes water quality analysis, winter maintenance best practices, and environmental issues related to anti-icing and deicing compounds on roadways. She is also the acting lab manager for the WTI Corrosion, Electrochemistry & Analysis Laboratory (CEAL). Ms. Fay holds a M.S. in Environmental Science and Health from the University of Nevada, and a B.S. in Earth Sciences from the University of California, Santa Cruz.

Michelle Akin, M.Sc., a Research Associate at WTI, has played a large role in the development of the Lewistown cold region transportation test bed, from defining the scope of work, to performing an inventory of current capabilities, and initial design of the facility. She will assist the planning and field investigation tasks of the proposed research. Ms. Akin holds a M.S. in Civil Engineering from Montana State University, and a B.S. in Environmental Resources Engineering from Humboldt State University in Arcata, California.

Tuan Anh Nguyen, Ph.D. is a Postdoctoral Research Associate at WTI specialized in electrochemistry and corrosion, with an emphasis on electro-active polymers and electrochemical and surface analytical techniques. He has fourteen years of experience in conducting engineering and science research, with demonstrated publications records and extensive project experience. His current research focus at WTI includes electro-active polymers for transportation applications and surface treatment of electrodes for microbial fuel cells. He holds his Ph.D. in Chemistry from University of Paris 7, France.

Jiang Huang, M.Sc. is a Research Associate specialized in statistics and data mining. Her current research focus at WTI includes road weather management, quality control of precipitation data, handling of missing data, and experimental design for field sampling. She holds her M.Sc. in Statistics from Montana State University - Bozeman.

Relevant Project Experience

WTI has developed a diverse portfolio of work that can support the Pooled Fund's needs for this research. This section describes some projects that have direct applicability to the work tasks described earlier or demonstrate the researchers' related project experience.

Synthesis of Information on Anti-icing and Pre-wetting for Winter Maintenance for the Pacific Northwest Snowfighters Association – The objectives of the project were to research current knowledge on the advantages and disadvantages of anti-icing and pre-wetting operations and to ensure a full understanding of why agencies had adopted these strategies. Funded by the PNS through WSDOT. Jan. 2005 – Aug. 2005. Principal Investigator: Dr. Xianming Shi.

Effect of Chloride-Based Deicers on Reinforced Concrete Structures: Phase I – The objectives of this research are to evaluate the effect of chloride-based deicers on reinforced concrete structures such as roadways and bridges operated by the Washington State Department of Transportation (WSDOT) and to determine whether or not reducing deicer corrosivity helps preserve the transportation infrastructure. Funded by the PNS through WSDOT. Dec. 2005 – December 2007. Principal Investigator: Dr. Xianming Shi.

ACRP Synthesis 11-03/Topic S10-03: Use and Corrosion Impacts of Airport Pavement Deicing – The objectives of this research are to report on how airports deice their airfield pavements, chemicals used, amounts applied, and evidence of associated corrosion or degradation of aircraft and airfield infrastructure, and to identify gaps in the existing knowledge base. Funded by the Airport Cooperative Research Program. March 2007 – November 2007. Principal Investigator: Dr. Xianming Shi (with support of M. Akin).

Evaluation of Alternate Anti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers – The objective of this project is to evaluate potassium acetate and sodium acetate/formate blend deicers (or possibly potassium formate) as alternative anti-icing and deicing compounds relative to NaCl salt-sand mixtures and $MgCl_2$ (baseline deicers), in terms of their effectiveness, performance, safety, ease of application, cost, impacts on pavements and structures, reactivity with other deicers, human health effects and environmental effects. Funded by the Colorado Department of Transportation. June 2006 – June 2008. Principal Investigator: Dr. Xianming Shi (with support of L. Fay).

Analysis of Maintenance Decision Support System (MDSS) Benefits and Costs – The objectives of this project are to assess the benefits and costs associated with implementation of MDSS by a state transportation agency, and to distill this information in a format that is accessible and actionable to transportation agency decision-makers and elected officials. A pooled-fund study led by the South Dakota Department of Transportation. Oct. 2006 – September 2007. Principal Investigator: Christopher Strong, P.E. (with Dr. Shi as Co-PI and support of L. Fay).

Aurora Cost Benefit for Weather Information in Winter Maintenance – The objective of this project is to provide a current benefit-cost assessment for weather information on winter maintenance. A pooled-fund study led by the Iowa Department of Transportation. May 2007 – May 2008. Principal Investigator: Christopher Strong, P.E. (with Dr. Shi as Co-PI and support of L. Fay).

Validating the Durability of Corrosion Resistant Mineral Admixture Concrete – The objectives of this project are to validate chloride diffusion coefficients of mineral admixture concrete mix designs currently specified by Caltrans for corrosion mitigation, and to verify the adequacy of existing measures to mitigate corrosion caused by exposure to marine environments and deicing salt applications. Funded by the California Department of Transportation. June 2006 – June 2009. Principal Investigator: Dr. Xianming Shi.

An Innovative Coating System for the Corrosion Prevention of Galvanized Steel - The objective of the project is to develop an innovative, environmentally friendly and self-repairing coating system for corrosion prevention of galvanized steel. Funded by the U.S. Research and Innovative Technology Administration. Jan. 2007 – Oct. 2007. Principal Investigator: Dr. Xianming Shi. Co-PI: Dr. Xiaodong He.

Mitigation of Moisture and Deicer Effects on Asphalt Thermal Cracking through Polymer Modification – The objectives of the project are to explore for the key factors that affect the cracking behavior of asphalt mixes at low service temperature in presence of moisture and deicers, to study the chemical and physical processes in which moisture and deicers affect and polymer materials improve tensile stress resistance in both mastic and IIZ of polymer modified asphalt, as well as to develop a micro-mechanistics based thermal cracking model of asphalt mixes. Funded by the U.S. Research and Innovative Technology Administration. Dec. 2006 – July 2007. Principal Investigator: Dr. Tongyan Pan (with Dr. Shi as co-PI).

Electrochemical Rehabilitation of Salt-Contaminated Concrete: A Laboratory Study – The objectives of the project are to preliminarily investigate some of the key factors affecting the performance of electrochemical chloride extraction (ECE) and electrical injection of corrosion inhibitors (EICI) and to validate a modeling framework that can guide the design of ECE/EICI. Funded by the U.S. Research and Innovative Technology Administration. Nov. 2006 – Sept. 2007. Principal Investigator: Dr. Xianming Shi.

An Autonomous and Self-Sustained Sensing System to Monitor Water Quality Near Highways – The objective of the project is to develop an autonomous and self-sustained sensing system that *in-situ* monitors environmental parameters in water bodies near highways for assessing the impact of highway runoff on these water bodies. Funded by the National Research Council, NCHRP-IDEA. May 2007 – Oct. 2008. Principal Investigator: Dr. Xianming Shi.

Synthesis of Vehicle-Based Winter Maintenance Technologies – The objective of this project was to identify all vehicle-mounted winter maintenance technologies indicating the state of development. Funded by the National Cooperative Highway Research Program. NCHRP Project 20-07/Task 200. Nov. 2005 – Sept. 2006. Principal Investigator: Dr. Xianming Shi.

Corrosion Inhibition Mechanisms at the Steel/Concrete Interface – The objective of the project was to investigate the corrosion and corrosion inhibition mechanisms at the steel/concrete interface in the absence and presence of corrosion inhibitors. Funded by the U.S. Research and Innovative Technology Administration. May 2005 – Dec. 2006. Principal Investigator: Dr. Xianming Shi.

Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water – The objective of the project was to develop a comprehensive document for the management of winter road traction materials on Montana highways so that impacts on the adjacent aquatic resources from such materials would be minimized. Funded by the Montana Department of Transportation. June 2003 – July 2004. Principal Investigator: Dr. Xianming Shi.

Evaluation of the UDOT Weather Operations / RWIS Program: Phase I – The objectives of this project were to examine the business case of the Utah Department of Transportation (UDOT) Weather Operations/ RWIS Program, and to preliminarily assess its effectiveness and benefits. Jointly funded by the U.S. Research and Innovative Technology Administration and UDOT. Aug. 2005 – Feb. 2007. Principal Investigator: Dr. Xianming Shi. *Winner of the ITS America 2007 Award (Category: Return on Investment).*

10. Researcher Resumes

XIANMING SHI, PH.D.
Program Manager, Western Transportation Institute
Associate Research Professor, Civil Engineering Department
College of Engineering, Montana State University, Bozeman, MT 59717
406-994-6486 (Phone); 406-994-1697 (Fax)
Xianming_S@coe.montana.edu

Objective
Research and mitigate winter and corrosion effects on transportation systems through innovation and multi-disciplinary partnerships

Education

2002	M.S., Industrial & Management Eng., Montana State University – Bozeman
1999-2000	Ph.D. Student, Environmental Eng., Montana State University – Bozeman
1999	Ph.D., Chemistry, Institute of Chemistry, Chinese Academy of Sciences, Beijing
1996	M.S., Applied Chemistry, Tianjin University, Tianjin, China
1993	B.S., Corrosion & Protection, Beijing Institute of Chemical Technology, Beijing, China

Key Qualifications
- Extensive project experience and dedicated interest in transportation research
- Multi-disciplinary background and diverse skills in corrosion and material sciences, chemistry, industrial engineering, and environmental engineering
- Principal Investigator (PI) on 20 research projects and Co-PI on 4 research projects funded by the U.S. Research and Innovative Technology Administration, National Cooperative Highway Research Program, Airport Cooperative Research Program, Pacific Northwest Snowfighters Association, Clear Roads, MDSS Pooled Fund, Aurora Consortium, and the state departments of transportation of California, Colorado, Iowa, South Dakota, Montana, Utah, Washington, and Wisconsin
- Strong capabilities and extensive (14+ years) experience in conducting engineering and science research, with demonstrated publications records
- Hands-on experience in project management and program development
- Strong communication (written & verbal), presentation, and training skills

Research Interests
- *Winter maintenance best practices*, especially performance measures, test protocols, evaluation of products and technologies, and decision support systems
- *Infrastructure durability in cold regions*, especially deicer impact on metals, concretes, and asphalts; behavior and effectiveness of corrosion mitigation measures; and nanoscience and nanotechnology applied to corrosion and materials integrity in transportation systems
- *Green highways*, especially the use of recycled materials, and best practices to reduce environmental impact of anti-icing/deicing and other maintenance activities

Professional Affiliations
- American Society of Civil Engineers (ASCE), Associate Member since 2007
- Materials Research Society (MRS), Member since 2006
- Society of Automotive Engineers (SAE), Member since 2006
- Transportation Research Board (TRB), National Academies, Individual Affiliate since 2005
- TRB Committee on Winter Maintenance (AHD65), Member since 2006
- TRB Committee on Corrosion (AHD45), Member since 2005

- TRB Committee on Polymer Concretes, Adhesives, and Sealers (AHD40), Member since 2005
- TRB Committee on Basic Research and Emerging Technologies Related to Concrete (AFN10), Member since 2005
- School of Materials Sci. & Eng., Tianjin University, Specially Invited Professor since 2005
- Association of Chinese Corrosion Engineers (ACCE) International, Member since 2004; Member of the Board of Directors since 2006
- National Association of Corrosion Engineers (NACE), Member since 2002
- North American Chinese Overseas Transportation Association (NACOTA), Member since 2007
- American Chemical Society (ACS), Past Member, 2006
- Institute of Transportation Engineers (ITE), Past Member, 2003-2006
- Institute of Industrial Engineers (IIE), Past Member 2000-2006
- American Society of Quality (ASQ), Past Member 2002-2004
- Chinese Society for Corrosion and Protection (CSCP), Past Member 1996-1999

Professional Training

- ITS Systems (Certificate by the Consortium for ITS Training and Education, University of Maryland), 2004
- ITS Telecommunications (Short course by the National Highway Institute), 2003

Employment History

7/1/07-Present *Associate Research Professor,* Civil Engineering Department, Montana State University – Bozeman

5/1/05-Present *Program Manager - Winter Maintenance & Effects*, Western Transportation Institute, Montana State University – Bozeman

7/1/04-4/30/05 *Research Scientist*, Western Transportation Institute, Montana State University – Bozeman

2/1/03-6/30/04 *Research Associate*, Western Transportation Institute, Montana State University – Bozeman

8/16/02-1/31/03 *Research Aide*, Western Transportation Institute, Montana State University – Bozeman

5/15/02-8/15/02 *Summer Intern*, Western Transportation Institute, Montana State University – Bozeman

- Database-driven webpage design, programming, and decision support. Tools used included: PHP, HTML, SQL, Microsoft Office, and Microsoft Visio

Spring 2002 G*raduate Teaching Assistant*, Department of Mechanical & Industrial Engineering, Montana State University – Bozeman

- I&ME 458: *Production and Engineering Management* - Topics included value stream mapping, inventory control, and lean manufacturing.

08/1999-12/2001 G*raduate Research Assistant*, Center for Biofilm Engineering, Montana State University – Bozeman

- Biomineralized Manganese Oxides Deposited on Passive Metals (Dr. Shi worked in this project funded by the U.S. Office of Naval Research and published 3 papers in top-rank academic journals as first author); A Novel Type of Microbial Fuel Cell

Utilizing Manganese-Oxidizing Bacteria (Dr. Shi participated in preliminary experiments and literature review that led to a research grant funded by the U.S. Department of Defense). Tools used included continuous flow bioreactors, potentiostats (advanced electrochemical systems), UV-Vis, ToF-SIMS, XPS, AFM, and SEM/EDS.

08/1996-07/1999 *Graduate Research Assistant*, Institute of Chemistry, Chinese Academy of Sciences, Beijing, China

- Mr. Shi was responsible for the overall development of a RTM-processable, thermosetting resin system with outstanding thermal resistance for aerospace applications. Programmed neural networks in C to model the synthesis-structure-property relationships for the resin system and successfully synthesized a resin system with desired properties. Tools used included DSC, TGA, FTIR, NMR, and HPLC.

09/1993-06/1996 *Graduate Research Assistant*, Department of Materials Science & Engineering, Tianjin University, Tianjin, China

- Mr. Shi was responsible for the development of a localized corrosion sensor suitable for a corrosion monitoring system in the sea environment as well as pH sensor and dissolved oxygen sensor.

Spring 1993 *Research Assistant*, Department of Applied Chemistry, Beijing Institute of Chemical Technology, Beijing, China

- Mr. Shi was responsible for the development of a solventless epoxy coating applicable to the inner wall of food containers

Project Experience – Current

Winter Maintenance & Effects

Development of Standardized Test Procedures for Evaluating Deicing Chemicals – The objective of this research is to develop and/or identify a series of standard laboratory testing procedures and ranges that can be used to evaluate the performance of deicing chemicals, additives and mixtures used on roadways and other transportation facilities. Funded by Clear Roads, a pooled-fund study led by the Wisconsin Department of Transportation. $100,000. Oct. 2007 – April 2009. Principal Investigator. (Co-PI: Dr. Tuan Anh Nguyen).

ACRP Synthesis 11-03/Topic S10-03: Impact of Airport Pavement Deicing Products on Aircraft and Airfield Infrastructure – The objectives of this research are to report on how airports chemically treat their airfield pavements for snow and ice control, evidence of associated corrosion or degradation of aircraft and airfield infrastructure, and to identify gaps in the existing knowledge base. Funded by the Airport Cooperative Research Program. $30,000. March 2007 – November 2007. Principal Investigator.

Effect of Chloride-Based Deicers on Reinforced Concrete Structures: Phase I – The objectives of this research are to evaluate the effect of chloride-based deicers on reinforced concrete structures such as roadways and bridges operated by the Washington State Department of Transportation (WSDOT) and to determine whether or not reducing deicer corrosiveness helps preserve the transportation infrastructure. Funded by WSDOT. $168,001. Dec. 2005 – June 2008. Principal Investigator.

Evaluation of Alternate Anti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers – The objective of this project is to evaluate potassium acetate and sodium acetate/formate blend deicers (or possibly potassium formate) as alternative anti-icing and deicing compounds relative to NaCl salt-sand mixtures and $MgCl_2$, in terms of their effectiveness, performance, safety, ease of application, cost, impacts on pavements and structures, reactivity with other deicers, human health effects, and environmental effects. Funded by the Colorado Department of Transportation. $100,000. June 2006 – June 2008. Principal Investigator. (Co-PI: Laura Fay).

Analysis of Maintenance Decision Support System (MDSS) Benefits and Costs – The objectives of this project are to assess the benefits and costs associated with implementation of MDSS by a state transportation agency, and to distill this information in a format that is accessible and actionable to transportation agency decision-makers and elected officials. Funded by the MDSS pooled-fund led by the South Dakota Department of Transportation. $155,000. Oct. 2006 – March 2008. Co-PI; Principal Investigator: Christopher Strong, P.E.

Aurora Cost Benefit for Weather Information in Winter Maintenance – The objective of this project is to provide a current benefit-cost assessment for weather information on winter maintenance. Funded by the Aurora pooled-fund led by the Iowa Department of Transportation. $125,000. March 2007 – March 2008. Co-PI; Principal Investigator: Christopher Strong, P.E.

Corrosion & Materials Integrity

Validating the Durability of Corrosion Resistant Mineral Admixture Concrete – The objectives of this project are to validate chloride diffusion coefficients of mineral admixture concrete mix designs currently specified by Caltrans for corrosion mitigation, and to verify the adequacy of existing measures to mitigate corrosion caused by exposure to marine environments and deicing salt applications. Funded by the California Department of Transportation. $390,121. June 2006 – June 2009. Principal Investigator. (Co-PI: Dr. Brett Gunnink).

An Innovative Coating System for the Corrosion Prevention of Galvanized Steel - The objective of the project is to develop an innovative, environmentally friendly and self-repairing coating system for corrosion prevention of galvanized steel. Funded by the U.S. Research and Innovative Technology Administration. $48,827. Jan. 2007 – Oct. 2007. Principal Investigator. (Co-PI: Dr. Xiaodong He).

Mitigation of Moisture and Deicer Effects on Asphalt Thermal Cracking through Polymer Modification – The objectives of the project are to explore for the key factors that affect the cracking behavior of asphalt mixes at low service temperature in presence of moisture and deicers, to study the chemical and physical processes in which moisture and deicers affect and polymer materials improve tensile stress resistance in both mastic and IIZ of polymer modified asphalt, as well as to develop a micro-mechanistics based thermal cracking model of asphalt mixes. Funded by the U.S. Research and Innovative Technology Administration. $47,770. Dec. 2006 – Dec. 2007. Co-PI; Principal Investigator: Dr. Tongyan Pan.

Electrochemical Rehabilitation of Salt-Contaminated Concrete: A Laboratory Study – The objectives of the project are to preliminarily investigate some of the key factors affecting the performance of electrochemical chloride extraction (ECE) and electrical injection of corrosion inhibitors (EICI) and to validate a modeling framework that can guide the design of ECE/EICI. Funded by the U.S. Research and Innovative Technology Administration. $34,403. Nov. 2006 – Sept. 2007. Principal Investigator. (Co-PI: Dr. Tongyan Pan).

WTI Corrosion, Electrochemistry & Analysis Laboratory (CEAL) – The objective of the project is to expand the capabilities of the current Materials Corrosion Laboratory to allow multi-disciplinary research related to *deicer impacts on water quality, pavements, as well as metals*. Funded by the U.S. Research and Innovative Technology Administration. $66,001. March 2007 – September 2008. Principal Investigator.

Green Highways

An Autonomous and Self-Sustained Sensing System to Monitor Water Quality Near Highways – The objective of the project is to develop an autonomous and self-sustained sensing system that *in-situ* monitors environmental parameters in water bodies near highways for assessing the impact of highway runoff on these water bodies. Funded by the National Research Council, NCHRP-IDEA. $120,000. With another $25,000 cost-shared by the U.S. Research and Innovative Technology Administration. May 2007 – Oct. 2008. Principal Investigator. (Co-PI: Dr. Hongwei Gao).

Using Reinforced Native Grass Sod for Biostrips, Bioswales, and Sediment Control – The objectives of the project are to evaluate the efficiency and cost-effectiveness of the reinforced native grass sod and to address issues related to its preparation, installation, establishment, and maintenance in the State of California. The use of native grass sod is anticipated to facilitate quick vegetation establishment and soil reinforcement, reduce the risk of non-native weeds and fire hazards, and thus reduce the use of herbicides. In addition, the native grass sod is expected to minimize the amount of maintenance and water treatment needed for the vegetation management. Funded by the California Department of Transportation. $276,519. Dec. 2004 – June 2008. Principal Investigator.

Surface Transportation Weather/ ITS

Validating Percent Wet Time Statewide – The objective of this project is to develop an updated county-based percentage wet time table for better identification of high wet collision concentration locations in California. It will also examine the automatic updating of the percent wet time annually and the highway milepost-based percentage wet time table. Funded by the California Department of Transportation. $197,584. June 2006 – March 2008. Principal Investigator. (Co-PI: Shaowei Wang, P.E.).

Project Experience - Past

Winter Maintenance & Effects

NCHRP Project 20-07/Task 200: Synthesis of Vehicle-Based Winter Maintenance Technologies – The objective of this project was to identify all vehicle-mounted winter maintenance technologies indicating the state of development. Funded by the National Cooperative Highway Research Program. $75,000. Nov. 2005 – Sept. 2006. Principal Investigator.

Synthesis of Information on Anti-icing and Pre-wetting for Winter Maintenance for the Pacific Northwest Snowfighters Association – The objectives of the project were to research current knowledge on the advantages and disadvantages of anti-icing and pre-wetting operations and to ensure a full understanding of why agencies had adopted these strategies. Funded by PNS through the Washington State Department of Transportation. $30,000. Jan. 2005 – Aug. 2005. Principal Investigator.

Materials Corrosion Laboratory: Evaluating Common Corrosion-inhibited Deicers – The objective of the project was to establish the research capabilities at WTI to tackle transportation-related corrosion issues, such as the corrosive effect of deicers to vehicles, pavements, and rebars in concrete structures. This “early winner” project established protocols for evaluating the corrosion rate of materials and performance of corrosion inhibitors. Funded by the U.S. Research and Innovative Technology Administration. $40,289. December 2003 – March 2005. Principal Investigator.

Corrosion & Materials Integrity

Investigating Innovative Research Opportunities Related to the Application of Electrochemistry in Transportation – The overall objectives of this project are to investigate innovative research opportunities related to the application of electrochemistry in transportation and to utilize and expand the research infrastructure and expertise available at the WTI Materials Corrosion Laboratory. Funded by the U.S.

Research and Innovative Technology Administration. $159,371. November 2005 – April 2007. Principal Investigator.

Corrosion Inhibition Mechanisms at the Steel/Concrete Interface – The objective of the project was to investigate the corrosion and corrosion inhibition mechanisms at the steel/concrete interface in the absence and presence of corrosion inhibitors. Funded by the U.S. Research and Innovative Technology Administration. $61,176. May 2005 – Dec. 2006. Principal Investigator. (Co-PI: Dr. Zhiyong Suo).

UTC Materials Corrosion Lab, Phase 1 – The objective of the project was to provide the essential research infrastructure in establishing a competitive Materials Corrosion Laboratory at WTI dedicated to the prevention, detection, monitoring, reduction and rehabilitation of materials corrosion and advanced materials/technologies to improve the durability of *transportation infrastructure in cold regions*. Funded by the U.S. Research and Innovative Technology Administration. $124,092. September 2005 – September 2006. Principal Investigator.

Green Highways

Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water – The objective of the project was to develop a comprehensive document for the management of winter road traction materials on Montana highways so that impacts on the adjacent aquatic resources from such materials would be minimized. Funded by the Montana Department of Transportation. $25,000. June 2003 – July 2004. Principal Investigator. (Co-PI: Dr. Otto Stein).

Surface Transportation Weather/ ITS

Evaluation of the UDOT Weather Operations / RWIS Program: Phase I – The objectives of this project were to examine the business case of the Utah Department of Transportation (UDOT) Weather Operations/ RWIS Program, and to preliminarily assess its effectiveness and benefits. Jointly funded by the U.S. Research and Innovative Technology Administration and UDOT. $53,500. Aug. 2005 – Feb. 2007. Principal Investigator. (Co-PI: Christopher Strong, P.E.). *The Program was the winner for ITS America 2007 Award for Best "Return on Investment".*

WeatherShare – The objective of the project was to streamline and integrate currently available road weather data into one single source easily accessible by incident responders and the traveling public. This relatively small ITS project followed a customized systems engineering process, and systems engineering tools such as a Project Plan, Concept of Operations, User Requirements Analysis, Configuration Management Plan, and Facilities Study Report are utilized to ensure the success. Funded by the California Department of Transportation. $200,000. July 2003 to December 2005. Final Principal Investigator.

Redding District Incident Management Responder Study – The objectives of the project were to provide the information elements, framework and pilot deployment of an incident information collection/incident support system centered on requirements of Caltrans District 2 field / TMC personnel and to provide the necessary hardware and communications infrastructure for the exchange of at-scene information and the distribution of incident support information. Funded by the California Department of Transportation. $150,000. July 2003 to June 2005. Co-PI; Principal Investigator: Douglas Galarus.

Statewide Coordinated Transportation Planning (DDPAC) – The objective of the project was to develop a comprehensive handbook that provides a step-by-step process allowing for social service agencies and local transportation providers to effectively coordinate their transportation services in Montana. Mr. Shi worked on tasks related to webpage programming and systems engineering from May 2002 to November 2002.

CANAMEX Smart Tourist Corridor – The objective of the project was to develop a vision for the smart tourist corridor that connects Mexico to Canada via Arizona, Nevada, Utah, Idaho, and Montana. Mr. Shi worked on tasks related to literature review, engineering economics, and technical writing from November 2002 to March 2004.

Frontier (FHWA Demonstration and Evaluation of ITS on the Rural Highway Environment) – The objective of the project was to prove successful transfer or application of advanced ITS technologies in rural two-lane highway environments through small-scale deployment and evaluation. Mr. Shi worked on tasks related to literature review, agency surveys, and technical writing from November 2002 to March 2004.

Greater Yellowstone Regional Traveler and Weather Information Systems (GYRTWIS) – The objective of the project was to develop short-term (5-year) recommendations for the expansion and improvement of Montana's traveler information systems. Mr. Shi worked as the lead GIS expert from December 2002 to March 2003.

Siskiyou Pass Traveler Information and Incident Management Evaluation – The objective of the project was to evaluate strategic ITS deployments throughout the Siskiyou Pass region including Highway Advisory Radio, Changeable Message Signs, Kiosks, Closed-Circuit Television Cameras and a Regional Incident Management Plan. Mr. Shi worked on tasks related to systems engineering from February 2003 to May 2003.

Presentations/Publications

Referred Journal Publications

1. Pan, T., Nguyen, T. A., and Shi, X. Assessment of Electrical Injection of Corrosion Inhibitor for Corrosion Protection of Reinforced Concrete. *Transportation Research Record (Journal of the Transportation Research Board)*, 2008, in press.
1. Liu, Y. and Shi, X. A Methodology for Parameter Estimation and Process Simulation of Electrochemical Chloride Extraction from Concrete. 2007, under revision.
2. He, X., and Shi, X. Chloride Permeability and Microstructure of Portland Cement Mortars Incorporating Nanomaterials. *Journal of Materials in Civil Engineering*, 2007, under review.
3. He, X., and Shi, X. Self-repairing Coating for Corrosion Protection of Aluminum Alloys. *Journal of Polymer Science Part A: Polymer Chemistry*, 2007, under review.
4. He, X., Pan, T., and Shi, X. Impact of Acetate-Based Deicers on Asphalt Concrete. *Materials Chemistry and Physics,* 2007, under review.
5. Nguyen, T.A., Lu, Y., Yang, X., and Shi, X. Carbon and Steel Surfaces Modified by *Leptothrix discophora* SP-6: Characterization and Implications. *Environmental Science & Technology*, 2007, in press.
6. Nguyen, T.A. and Shi, X. An Electrochemical and Microstructural Characterization of Steel-Reinforced Concrete Admixed with Corrosion Inhibitors. *Journal of Materials in Civil Engineering*, 2007, under review.
7. Shi, X., Suo, Z., and Nguyen, T.A. Corrosion Inhibition Mechanisms at the Steel-Concrete Interface: An EDS/XPS Study. *Corrosion Science*, 2007, under preparation.
8. Shi, X., O'Keefe, K., Wang, S., and Strong, C. The Utah Department of Transportation's Weather Operations/RWIS Program: A Benefit-Cost Evaluation, *ASCE Journal of Transportation Engineering*, 2007, under review.
9. Shi, X., Schillings, P. and Boyd, D. Applying Artificial Neural Networks and Virtual Experimental Design to Quality Improvement of Two Industrial Processes. *International Journal of Production Research*, 2003, 42(1): 101.

10. Shi, X., Avci, R. and Lewandowski, Z. Comparative Study in Chemistry of Microbially and Electrochemically Initiated Pits of Type 316L Stainless Steel. *Corrosion Science*, 2003, 45(11): 2577.
11. Shi, X., Avci, R. and Lewandowski, Z. Biomineralized Manganese and Iron Oxides on Passive Metals: Their Chemistry and Consequences for Material Performance. *Corrosion*, 2002, 58(9): 728.
12. Shi, X., Avci, R. and Lewandowski, Z. Electrochemistry of Passive Metals Modified by Manganese Oxides Deposited by *Leptothrix Discophora*: Two-step Model Verified by TOF-SIMS. *Corrosion Science*, 2002, 44(5): 1027.
13. Lewandowski, Z., Avci, R., Geiser, M., Shi, X., Braughton, K., and Yurt, N. Biofouling and Corrosion of Stainless Steels in Natural Waters. *Water Science and Technology: Water Supply*, 2002, 2(4): 65.
14. Yan, Y., Shi, X., Liu, J., Zhao, T., and Yu, Z. A Thermosetting Resin System Based on Novolak and Bismaleimide for Resin-Transfer Molding, *Journal of Applied Polymer Science*, 2002, 83(8): 1651
15. Shi, X., Zhao, T., Wu, Y. and Yu, Y. Neural Networks Applied to Prediction of Mechanical Properties of Glass Fiber-Reinforced Phenolic Resins. *Polymeric Material Science and Engineering (Chinese)*, 2000, 16(4): 117.
16. Shi, X., Zhao, T., Wu, Y., Yu, Y. and Li, Z. Study on Thermosetting Phenolic Resins Using Neural Networks. *Computers and Applied Chemistry (Chinese)*, 1998, 15(5): 315.
17. Shi, X., Wu, Y. and Yu, Y. Recent Studies on Phenolic Resins Used as Heat-resistant Materials. *Polymer Bulletin (Chinese)*, 1998, (4): 59.
18. Hu, F., Shi, X., Qu, D. and Li, Z. Studies on the Correlation between Structure Parameters and Corrosion Inhibiting Properties of Benzeneamine and Its Derivatives via Neural Networks. *Journal of Chinese Society for Corrosion & Protection (Chinese)*, 1999, 19(1): 33.
19. Hu, F., Qu, D., Shi, X., and Li, Z. Neural Network Study on the Correlation between Electronic Structure and Corrosion Inhibiting Properties of Isoquinoline and Its Derivatives. *Journal of Chinese Society for Corrosion & Protection (Chinese)*, 1998, 18(4): 281.

Refereed Conference Proceedings

1. Shi, X. and Nguyen, T. A. Effect of Nanomaterials on the Anti-corrosion Performance of Epoxy Coating. Under preparation.
2. He, X., and Shi, X. Chloride Permeability and Microstructure of Portland Cement Mortar Incorporating Nanomaterials. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-1041.
3. He, X., and Shi, X. Self-repairing Coating for Corrosion Protection of Aluminum Alloys: A Proof-of-Concept Using Cagelike Smart Particles. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-0187.
4. Pan, T., Shi, X., and Nguyen, T. A., Finite Element Modeling of Ionic Transport in Concrete under an Externally Applied Electric Field. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-2169.
5. Pan, T., Nguyen, T. A., and Shi, X. Assessment of Electrical Injection of Corrosion Inhibitor for Corrosion Protection of Reinforced Concrete. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-1973.
6. Fay, L., Volkening, K., Gallaway, C., and Shi, X. Performance and Impacts of Current Deicing and Anti-icing Products: User Perspective versus Experimental Data. *CD-ROM of the 87thAnnual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-1382.
7. Pan, T., He, X., and Shi, X. Laboratory Investigation of Acetate-based Deicing/Anti-icing Agents Deteriorating Airfield Asphalt Concrete. 83rd Annual Meeting. Philadelphia, Pennsylvania, 2008, Paper number 08-13.
8. Huang, J., Wang, S., and Shi, X. Estimating the Wet-Pavement Exposure with Historical Precipitation Data in the State of California. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-2949.

9. Veneziano, D., Wang, S., and Shi, X. Synthesis of State Practices Regarding Wet Pavement Crash Analysis. *The 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, under review.
10. Strong, C., and Shi, X. Benefit-Cost Analysis of Weather Information for Winter Maintenance: A Case Study. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-1359.
11. Nguyen, T.A., Lu, Y., Song, S., and Shi, X. Carbon and Steel Surfaces Modified by *Leptothrix discophora* SP-6: Characterization and Implications. The Nature of Design - Utilizing Biology's Portfolio. MRS Proceedings Volume 1008E, Paper Number 1008-T05-10. *2007 Materials Research Society (MRS) Spring Meeting & Exhibit*, April 9-13, 2007, San Francisco, CA.
12. Shi, X., El Ferradi, N., and Strong, C. Fixed Automated Spray Technology for Winter Maintenance: The State of the Practice in North America. *The 86th Annual Meeting of Transportation Research Board*, Washington D.C., 2007.
13. Shi, X., Larson, R., Strong, C., Kack, D.W., Cuelho, E.V., Fay, L., El Ferradi, N., Seshadri, A., and O'Keefe, K. Vehicle-Based Sensor Technologies for Winter Maintenance: A Critical Review. *The 86th Annual Meeting of Transportation Research Board*, Washington D.C., 2007.
14. Strong, C., El Ferradi, N., and Shi, X. State-of-The-Practice of Automatic Vehicle Location for Winter Maintenance Operations. *The 86th Annual Meeting of Transportation Research Board*, Washington D.C., 2007.
15. Shi, X., Wang, S., Turnbull, I., Chu, M., and Albert, S. A Regional Pilot Weather Information System for Surface Transportation and Incident Management. *Proceedings of the Transportation Research Board Annual Meeting*, January 22-26, 2006, Washington, D.C.
16. O'Keefe, K., and Shi, X. Anti-icing and Pre-wetting: Improved Methods for Winter Highway Maintenance in North America. *Proceedings of the Transportation Research Board Annual Meeting*, January 22-26, 2006, Washington, D.C.
17. Shi, X., Wang, S., Turnbull, I., Chu, M., and Albert, S. WeatherShare: An Integrated, User-friendly Surface Transportation Weather System for Northern California. *12th World Congress on Intelligent Transportation Systems.* San Francisco, California. November 6-10, 2005.
18. Shi, X. and Song, S. Evaluating the Corrosivity of Chemical Deicers: An Electrochemical Technique. *16th International Corrosion Congress*. Beijing, China. September 19-24, 2005.
19. Shi, X., Staples, J.M., and Stein, O. Managing Winter Traction Materials on Roadways Adjacent to Bodies of Water: Challenges and Opportunities. *Environmental Stewardship in Transportation through Waste Management, Materials Reuse and EMS: 2005 Summer TRB Committee ADC60 Conference*. Charlotte, North Carolina. July 17-19, 2005.
20. Shi, X. The Use of Road Salts for Highway Winter Maintenance: An Asset Management Perspective. *2005 ITE District 6 Annual Meeting*. Kalispell, Montana. July 10-13, 2005.
21. Shi, X., Avci, R. and Lewandowski, Z. Biomineralized Manganese and Iron Oxides on Passive Metals: Their Chemistry, Distribution, and Consequences for Material Performance. Presented Paper 02456, *CORROSION/2002 Annual Conference and Exhibition.* Denver, Colorado. April 7-11, 2002.
22. Lewandowski, Z., Avci, R., Geiser, M., Shi, X., Braughton, K., and Yurt, N. Biofouling and Corrosion of Stainless Steels in Natural Waters. *Proceedings of 2nd World Water Congress*. Berlin, Germany. October 15-19, 2001.
23. Shi, X., and Song, S. Development Study on a Corrosion-Monitoring Sensor for Metal Structures in the Sea. *Proceedings of 9th National Symposium on Electrochemistry*. Tai-an, China. Sept. 1997.
24. Zhao, T., Shi, X., Liu, J., Zhu, W. and Wu, Y. HPLC Applied to Study on Chemical Structures of Phenolic Resins. *Proceedings of China'97 Symposium on Adhesion & Sealing Techniques*. Beijing, China. October 1997.

Technical Reports and Articles

1. Shi, X. Impact of Airport Pavement Deicing Products on Aircraft and Airfield Infrastructure. Draft final report prepared for the Airport Cooperative Research Program, Transportation Research Board, National Academies, Washington, D.C., August 2007.
2. Shi, X., and Fay, L., Evaluation of Alternate Anti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers. An interim report prepared for the Colorado Department of Transportation, Denver, CO, July 2007.
3. Fay, L., Shi, X. Performance and Impacts of Deicing and Anti-icing Products: User-Perceived Ranking. A report prepared for the Colorado Department of Transportation, Denver, CO, May 2007.
4. Shi, X., O'Keefe, K., Wang, S., and Strong, C. Evaluation of Utah Department of Transportation's Weather Operations/RWIS Program: Phase I. A final report prepared for the Utah Department of Transportation, Salt Lake, UT, February, 2007.
5. Liu, Y., Reichert, M., and Shi, X. Transport of Chlorides and Inhibitors in Concrete: A Critical Review. A report prepared for the Washington State Department of Transportation, Olympia, WA, January 2007.
6. Shi, X., Fay, L., and Pan, T. Corrosion of Deicers to Reinforcing Steel in Concrete Structures: A Critical Review. A report prepared for the Colorado Department of Transportation, Denver, CO, December 2006.
7. Fay, L., Shi, X., and Pan, T. Environmental Impacts of Deicers: A Critical Review. A report prepared for the Colorado Department of Transportation, Denver, CO, December 2006.
8. Pan, T., Fay, L., and Shi, X. Deicer Impacts on Pavement Materials: A Critical Review. A report prepared for the Colorado Department of Transportation, Denver, CO, December 2006.
9. Strong, C., Shi, X., and Patterson, R. UDOT's Weather Operations/RWIS Program. *ITS Rocky Mountain Chapter Newsletter*, 2007, 7(2): 8-11.
10. Shi, X., Pan, T., Veneziano, D., Huang, J., Ghosh, M., and Kumar, M. Estimating the Wet Pavement Exposure with Precipitation Data: Literature Review and Current Practices. A report prepared for the California Department of Transportation, Sacramento, CA, December 2006.
11. Transportation Research Board, Basic Research and Emerging Technologies Related to Concrete Committee. *Control of Cracking in Concrete: State of the Art***.** Transportation Research Circular E-C107. Washington, DC, October 2006.
12. Shi, X., Strong, C., Larson, R., Kack, D.W., Cuelho, E.V., El Ferradi, N., Seshadri, A., O'Keefe, K., and Fay, L.E. Vehicle-Based Technologies for Winter Maintenance: The State of the Practice. Final Report for the NCHRP Project 20-07/Task 200. Prepared for the National Cooperative Highway Research Program (NCHRP), Washington D.C., September 2006.
13. O'Keefe, K. and Shi, X. Synthesis of Information on Anti-icing and Pre-wetting for Winter Highway Maintenance Practices in North America. Final Report. Prepared for the Pacific Northwest Snowfighters Association in Collaboration with the Washington State Department of Transportation. August 2005.
14. Shi, X. WeatherShare Concept of Operations. Version 2.0 – Baseline. Prepared for California Department of Transportation. Sacramento, CA, April 2005.
15. Shi, X. WeatherShare Project Plan. Version 2.0 – Baseline. Prepared for California Department of Transportation. Sacramento, CA, April 2005.
16. Staples, J.M., Gamradt, L., Stein, O., and Shi, X. Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water. Final Report. Prepared for the Montana Department of Transportation. Helena, MT, December 2004. FHWA/MT-04-008/8117-19.
17. Albert, S., Wright, P.M., Taylor, J.E., Shi, X., and Lee, S. CANAMEX Smart Tourist Corridor. Final Report. Prepared for the CANAMEX Corridor Coalition in Collaboration with the U.S. Federal Highway Administration. March 2004.
18. Kelly, S., Kack, D., Shi, X., and Ballard, L. Montana Coordinated Transportation Handbook. Prepared for the Montana Council on Developmental Disabilities. Helena, MT, 2003.

Presentations

1. Shi, X., FAST and Vehicle-based Winter Maintenance Technologies: The State of the Practice. Invited Presentation. *12th Eastern Snow Expo.* August 30, 2007, Columbus, OH.
2. Shi, X., Impact of Airport Pavement Deicing Products on Aircraft and Airfield Infrastructure. Invited Presentation. *16th Annual Aircraft and Airfield Deicing and Stormwater Conference*. August 5-7, 2007, Baltimore, MD.
3. Shi, X., Larson, R., Strong, C., Kack, D.W., and Cuelho, E.V. Vehicle-Based Sensor Technologies for Smart Snowplows. Poster Session 2. *2007 ITS America Annual Meeting & Expo*, June 4-6, 2007, Palm Springs, CA.
4. Shi, X., Strong, C., O'Keefe, K., Wang, S., Little, C., and Patterson, R. The Next Stage in Improving Road Weather Forecasting: UDOT's Weather Operations/RWIS Program. Poster Session 2. *2007 ITS America Annual Meeting & Expo*, June 4-6, 2007, Palm Springs, CA.
5. Nguyen, T.A., Lu, Y., Song, S., and Shi, X. Carbon and Steel Surfaces Modified by *Leptothrix discophora* SP-6: Characterization and Implications. Poster Session T. *2007 Materials Research Society (MRS) Spring Meeting & Exhibit*, April 9-13, 2007, San Francisco, CA.
6. Shi, X., El Ferradi, N., and Strong, C. Fixed Automated Spray Technology for Winter Maintenance: The State of the Practice in North America. *The 86th Annual Meeting of Transportation Research Board*, Washington D.C., 2007.
7. Shi, X., Larson, R., Strong, C., Kack, D.W., Cuelho, E.V., Fay, L., El Ferradi, N., Seshadri, A., and O'Keefe, K. Vehicle-Based Sensor Technologies for Winter Maintenance: A Critical Review. *The 86th Annual Meeting of Transportation Research Board*, Washington D.C., 2007.
8. Shi, X., Strong, C., Larson, R.E., Kack, D.W., and Cuelho, E.V. Synthesis of Vehicle-Based Winter Maintenance Technologies. *National Rural ITS Conference 2006*, August 13-16, 2006, Big Sky, Montana.
9. Shi, X., Wang, S., Turnbull, I., Chu, M., and Albert, S. Integrating the Surface Transportation Weather Information: An ITS System for Northern California. *National Rural ITS Conference 2006*, August 13-16, 2006, Big Sky, Montana.
10. O'Keefe, K., Strong, C., Wang, S., and Shi, X. Evaluation of UDOT's Weather Operations/RWIS Program. *National Rural ITS Conference 2006*, August 13-16, 2006, Big Sky, Montana.
11. Shi, X., Staples, J.M., and Stein, O. Highway Runoff Best Management Practices and Winter Traction Materials Management: Cold Regions Perspective. *Transportation Research Board Annual Meeting*, January 22-26, 2006, Washington, D.C. Session 360, Sponsored by the Committee on Waste Management in Transportation.
12. O'Keefe, K., and Shi, X. Anti-icing and Pre-wetting: Improved Methods for Winter Highway Maintenance in North America. *Transportation Research Board Annual Meeting*, January 22-26, 2006, Washington, D.C. Winter Maintenance Committee Meeting.
13. Shi, X., Wang, S., Turnbull, I., Chu, M., and Albert, S. A Regional Pilot Weather Information System for Surface Transportation and Incident Management. *Transportation Research Board Annual Meeting*, January 22-26, 2006, Washington, D.C. Session 410, Sponsored by the Surface Transportation Weather Task Force.
14. Shi, X., Wang, S., Turnbull, I., Chu, M., and Albert, S. WeatherShare: An Integrated, User-friendly Surface Transportation Weather System for Northern California. *12th World Congress on Intelligent Transportation Systems.* San Francisco, California. November 6-10, 2005.
15. Shi, X. Durability and Life Prediction of Concretes Admixed with Corrosion Resistant Minerals. Invited presentation. School of Material Science & Engineering. Tianjin University, Tianjin, China. September 28, 2005.
16. Shi, X. and Song, S. Evaluating the Corrosivity of Chemical Deicers: An Electrochemical Technique. *16th International Corrosion Congress*. Beijing, China. September 19-24, 2005.
17. Shi, X., Staples, J.M., and Stein, O. Managing Winter Traction Materials on Roadways Adjacent to Bodies of Water: Challenges and Opportunities. *Environmental Stewardship in Transportation*

through Waste Management, Materials Reuse and EMS: 2005 Summer TRB Committee ADC60 Conference. Charlotte, North Carolina. July 17-19, 2005.
18. Shi, X. The Use of Road Salts for Highway Winter Maintenance: An Asset Management Perspective. *2005 ITE District 6 Annual Meeting*. Kalispell, Montana. July 10-13, 2005.
19. Shi, X. The Use of Road Salts for Highway Winter Maintenance: An Asset Management Perspective. Invited presentation. *Salt Strategy Meeting*. Washington Department of Transportation, Olympia, Washington. July 29, 2004.
20. Shi, X. Materials Corrosion in Transportation: Opportunities and Challenges. Western Transportation Institute, Bozeman, Montana. April 15, 2004.
21. Shi, X., Avci, R., and Lewandowski, Z. Microbially Deposited Manganese and Iron Oxides on Passive Metals: Their Chemistry, Distribution, and Consequences for Material Performance. *Winter 2002 CBE Technical Advisory Committee (TAC) Conference*, Center for Biofilm Engineering, Bozeman, Montana. February 14-15, 2002.

Honors and Other Activities

- Outstanding Research Award, College of Engineering, Montana State University, 2005.
- Paper Reviewer, Transportation Research Board, 2005 – Present
- Proposal Reviewer (invited by the Midwest Regional University Transportation Center), 2004.
- Co-organizer, Corrosion Forum by the Pacific Northwest Snowfighters Association, at WTI/MSU, December 2005.
- Book Proposal Reviewer (invited by Marcel Dekker, Inc.), *Quality Assurance Engineering for Software & E-Commerce*, 2003.
- Engineer-In-Training Certification, State of Montana, 2002 – Present, License #16066
- Honorary Citizenship, City of Bozeman, MT, 2000, recognized for the enthusiasm shown in furthering our mutual cultural understanding, while an International Student at Montana State University.
- Chairman, Chinese Students and Scholars Association at MSU-Bozeman, 1999 – 2000
- Outstanding Student, Beijing Institute of Chemical Technology, 1992 – 1993

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Education

2006	M.S., Environmental Science & Health, University of Nevada, Reno; 2006.
1999	B.S., Earth Sciences, University of California, Santa Cruz, 1999.
(2003)	Course work in Biology, Sierra Nevada College; Incline Village, Nevada.

Key Qualifications

- Five years laboratory and field research experience, specializing in environmental sciences including field studies, stream inventory studies, fish surveys, stream-bank stability studies, and road decommissioning studies and conducting laboratory experiments using analytical equipment in the field of mercury research.
- Experience facilitating partnerships among public and private agencies, and the general public on a variety of environmental issues.
- Examining the environmental implications of anti-icing and deicing compounds on roadways including the fate and transport of deicers, and developing best practices in winter highway maintenance.
- Extensive outreach experience conducting surveys and interviews

Research Interests

- Winter maintenance best practices
- Environmental impacts of deicers to vegetation, soil, and water
- Deicer impacts to metals, concrete, and asphalts
- Use of road weather information technology

Professional Affiliations

- Transportation Research Board (TRB), Individual Affiliate since 2006

Employment History

7/1/2007-present	*Research Scientist*, Western Transportation Institute, Montana State University
7/1/2006-6/30/2007	*Research Associate*, Western Transportation Institute, Montana State University
2004-2006	*Research Assistant*, University of Nevada, Reno
2004	*Laboratory Technician*, Biogeochemistry Laboratory, University of Nevada, Reno
2002	*Field Technician*, Six Rivers National Forest, Eureka, California
2002	*Americorps Volunteer*, Watershed Stewards Project, Six Rivers National Forest, Eureka, California
2000-2001	*Weekend Administrator, Program Coordinator, Instructor*, Guided Discoveries, Idylwild, California

1999 *Mentor*, Affinity Mentorship Project, La Honda, California

1998-1999 *Laboratory Technician*, Stable Isotope Laboratory, University of California, Santa Cruz

Project Experience-Current

Evaluation of Alternate Anti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers (CDOT)-This project includes a literature review of currently used chloride and acetate based deicers, including lab and field testing, and providing a concise comparison of the deicers. My role in this project includes an assessment of the environmental implications of deicer use including the fate and transport analysis of the deicer chemical components, as well as the supervision of fellowship students aiding in the research. Co-Principal Investigator.

Electrochemical Rehabilitation of Salt-Contaminated Concrete: A Laboratory Study – The objectives of the project are to preliminarily investigate some of the key factors affecting the performance of electrochemical chloride extraction (ECE) and electrical injection of corrosion inhibitors (EICI) and to validate a modeling framework that can guide the design of ECE/EICI. Funded by the U.S. Research and Innovative Technology Administration. Nov. 2006 – Sept. 2007. My role in this project includes sample preparation, processing and analytical analysis of the samples and data, as well as supervising undergraduate research students.

Analysis of MDSS Benefits and Cost for South Dakota-This project is analyzing the costs and benefits associated with Maintenance Decisions Support System (MDSS). My role in this project includes interviewing Department of Transportation (DOT) professionals regarding their experience with MDSS. This information will aid in the creation of the methodology that will used in the cost benefit analysis of MDSS.

Dust Stabilization and Suppression Summit-The first national conference on Dust Stabilization and Suppression is being coordinated by WTI with the help of the researchers, practitioners and industry members in this field. My role in this project includes coordinating meetings, helping to establishing the advisory panel, and planning of the summit.

Validating the Durability of Corrosion Resistant Mineral Admixture Concrete-This research project is validating chloride diffusion coefficients of mineral admixture concrete mix designs currently specified by Caltrans for corrosion mitigation, and verifying the adequacy of existing measures to mitigate corrosion caused by exposure to marine environments and deicing salt applications. My role in this project includes sample preparation, recording of data and project coordination.

NCHRP Project 20-07/Task 200: Synthesis of Vehicle-Based Winter Maintenance Technologies – The objective of this project was to identify all vehicle-mounted winter maintenance technologies indicating the state of development. Funded by the National Cooperative Highway Research Program.

RWIS Usage in Alaska-This project is investigating the current use of the RWIS network in Alaska by DOT professionals for measuring current and historical weather conditions on highway segments across the state. This will be accomplished through face-to-face interviews with several Alaska DOT&PF stakeholders. My role in this project is to conduct a portion of in person interviews in Alaska and present the concept of the project at a conference in Alaska.

Aurora Cost Benefit for Weather Information in Winter Maintenance – The objective of this project is to provide a current benefit-cost assessment for weather information on winter maintenance. A pooled-fund study led by the Iowa Department of Transportation.

ACRP Synthesis 11-03/Topic S10-03: Use and Corrosion Impacts of Airport Pavement Deicing – The objectives of this research are to report on how airports deice their airfield pavements, chemicals used, amounts applied, and evidence of associated corrosion or degradation of aircraft and airfield infrastructure, and to identify gaps in the existing knowledge base. Funded by the Airport Cooperative Research Program.

Publications

1. Strong, C. and Fay, L., RWIS Usage Report. A Final Report prepared for the Alaska Department of Transportation and Public Facilities Division of Program Development, Juneau, AK, September 2007.
2. Fay, L., Volkening, K., Gallaway, C., and Shi, X. Performance and Impacts of Current Deicing and Anti-icing Products: User Perspective versus Experimental Data. *The 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008. Paper # 08-1382.
3. Shi X., and Fay L., Evaluation of Alternate Anti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers. An interim report prepared for the Colorado Department of Transportation, Denver, CO, July 2007.
4. Fay, L. and M.S. Gustin. 2007. Investigation of mercury accumulation in cattails growing in constructed wetland mesocosms. Wetlands (accepted).
5. Fay L., Shi X. Performance and Impacts of Deicing and Anti-icing Products: User-Perceived Ranking. A report prepared for the Colorado Department of Transportation, Denver, CO, May 2007.
6. Shi X., Fay L., and Pan T. Corrosion of Deicers to Reinforcing Steel in Concrete Structures: A Critical Review. A report prepared for the Colorado Department of Transportation, Denver, CO, December 2006.
7. Fay L., Shi X., and Pan T. Environmental Impacts of Deicers: A Critical Review. A report prepared for the Colorado Department of Transportation, Denver, CO, December 2006.
8. Pan T., Fay L., and Shi X. Deicer Impacts on Pavement Materials: A Critical Review. A report prepared for the Colorado Department of Transportation, Denver, CO, December 2006.
9. Shi X., Strong C., Larson R., Kack D.W., Cuelho E.V., El Ferradi N., Seshadri A., O'Keefe K., and Fay L.E. Vehicle-Based Technologies for Winter Maintenance: The State of the Practice. Final Report for the NCHRP Project 20-07/Task 200. Prepared for the National Cooperative Highway Research Program (NCHRP), Washington D.C., September 2006.
10. Shi X., Larson, R., Strong, C., Kack, D.W., Cuelho, E.V., Fay, L., El Ferradi, N., Seshadri, A., and O'Keefe, K. Vehicle-Based Sensor Technologies for Winter Maintenance: A Critical Review. *The 86th Annual Meeting of Transportation Research Board*, Washington D.C., 2007.
11. Fay, L. and M.S. Gustin. 2007. Assessing the Influence of Different Atmospheric and Soil Mercury Concentrations on Foliar Mercury Concentrations. Water, Air and Soil Pollution 181:373-384.
12. Fay, L. Identifying the Sources of Mercury in Deciduous, Wetland and Evergreen Plants. Masters Thesis. University of Nevada, Reno. Aug. 2006.

Honors and Other Activities

Science Award- Sierra Nevada College
Dean List Highest Honors- Sierra Nevada College

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Education

2006 M.S., Civil Engineering, Montana State University – Bozeman (GPA 3.97)
2004 B.S., Environmental Resources Engineering, Humboldt State University, Arcata, CA (GPA 3.83)

Key Qualifications

- Multi-disciplinary background of civil and environmental engineering, mathematics and engineering mechanics
- Extensive project experience in transportation research

Research Interests

- Roadway infrastructure maintenance and materials
- Sensor networks and data acquisition systems for infrastructure monitoring
- Water Treatment and Design
- Environmental impacts of transportation
- Use of recycled materials in transportation systems

Professional Affiliations

- Transportation Research Board (TRB), National Academies, Individual Affiliate since 2007
- Society of Women Engineers (SWE), Past Member 2002-2006

Employment History

5/8/06-Present	*Research Associate* (Infrastructure Maintenance & Materials), Western Transportation Institute, Montana State University – Bozeman
8/1/04-5/31/06	*Graduate Teacher Assistant*, Civil Engineering Department, Montana State University – Bozeman
2/1/06-4/30/06	*Graduate Assistant*, Western Transportation Institute, Montana State University – Bozeman
6/1/03-8/31/03	*Undergraduate Research Student*, Research Experience for Undergraduates program, Western Transportation Institute, Montana State University – Bozeman
6/1/02-8/15/02	*Intern*, Manufacturing Department and Health and Human Services Department, Edwards Lifesciences, Irvine, CA

Project Experience - Selected

Development of a Cold Region Rural Transportation Research Test Bed in Lewistown, Montana - The objectives of this project are to plan, design, and build a transportation research test bed. Tasks include an inventory of existing test beds, creating an advisory committee, performing a requirements analysis, developing a detailed design, and construction. Funded by USDOT Office of Innovation, Research and Education. September 2006 – September 2010. Principal Investigator: Eli Cuelho

Investigating Innovative Research Opportunities Related to Highway Infrastructure Design and Maintenance – The objectives of this research are to pursue research related to highway infrastructure, including cost-effective pavement maintenance, use of geosynthetics in new and rehabilitated structures, and instrumentation and monitoring of transportation infrastructure. Funded by USDOT Office of Innovation, Research and Education. January 2004 – September 2006. Principal Investigator: Eli Cuelho

Preventive Maintenance Treatments: A Synthesis of Highway Practice – The objectives of this research are to review the literature and survey DOT agencies to assess the cost-effectiveness of preventive maintenance treatments for flexible pavements, including the extension to pavement life. Funded by Montana Department of Transportation. May 2005 – June 2006. Principal Investigator: Eli Cuelho. Co-PI: Dr. Robert Mokwa

Publications

1. Western Transportation Institute, *Basic Information on Typical Sensors Used to Monitor Bridges*, Handout for the Transportation Research Board 86th Annual Meeting, Workshop #107: Making Sense of Sensors Used to Monitor Bridges, January 21, 2007.
2. Cuelho, E.V., Mokwa, R.L., and Akin, M.R. *Preventive Maintenance Treatments of Flexible Pavements, A Synthesis of Highway Practice*, Final Report, Montana Department of Transportation, October 2006.
3. Strong, C., Kack, D., Kumar, M., Akin, M., and Albert, S. *Moose-Wilson Corridor Transportation Assessment*, Final Technical Report, Grand Teton National Park, April 2006
4. Livesey, M.R., Diaz, C.A., and Williams, T.K. "Advancing Airport Security Through Optimization and Simulation," *The UMAP Journal, the Journal of Undergraduate Mathematics and Its Applications*, 2003, 24(2): 141.

Honors and Other Activities

- Mary & Robert Sanks Graduate Fellowship recipient, 2005-2006
- Mary & Robert Sanks Graduate Fellowship, Presidential Graduate Scholarship, and John H and Rosalie L Morrison Scholarship recipient, 2004-2005
- Outstanding Environmental Resources Engineering Graduate, Humboldt State University, 2004
- Engineer-In-Training Certification (License #117815), State of California, 2003
- Judged Outstanding in Interdisciplinary Contest in Modeling, sponsored by Consortium for Mathematics and its Applications (COMAP), publication followed, 2003
- Member of Humboldt State University's water treatment competition team, 2003.
- Vice President of Planning for College Success, HSU student chapter of National Society of Collegiate Scholars, 2002-2004
- Freshman Chemistry Achievement Award, bestowed Handbook of Chemistry and Physics from CRC Press, 1999

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Education
Ph.D. *Chemistry*, University of Paris 7, Paris, France (2003)
B.S. *Physics*, Hanoi University, Hanoi, Vietnam (1992)

KEY QUALIFICATIONS
- Extensive project experience and dedicated interest in material science research
- Multi-disciplinary background and diverse skills in corrosion science and engineering, materials science, microstructure analysis…
- Strong capabilities and extensive (15 years) experience in conducting engineering and science research, with demonstrated publications records

Research Interests
- Corrosion and protection of metals
- Materials analysis methods (surface analysis techniques): SEM, EDX, TEM, AFM, XPS, FTIR, Raman, Scanning probe techniques…
- Electromaterials: Conducting polymer and its composites; Carbon nanotube and its composites; Nanostructured materials, Sensors (humidity and temperature sensors, corrosion sensor, bio-sensors); Energy conversion and storage (microbial fuel cell, solar cell)

Professional Affiliations
- Materials Research Society, Member since 2006
- Member, Australian Research Council Nanotechnology Network, Australia, since 2005

Employment History
- August 2006 – July 2007: *Postdoctoral research associate*, Corrosion and Electrochemical Laboratory, Western Transportation Institute, Montana State University, USA
- May 1994 - Present: *Research Scientist,* Institute for Tropical Technology, Vietnamese Academy of Science and Technology.
- November 2005 – April 2006: *Visiting fellow*, Intelligent Polymer Research Institute, University of Wollongong, Australia
- September 2004- December 2004 : *Visiting researcher*, Alloys Design Laboratory, School of Materials and Engineering, Seoul National University, South Korea
- October 1998 – December 2002: *PhD. Student*, Laboratory ITODYS (Interfaces, Treatment, Organization and Dynamics of Systems, UMR CNRS, University Paris 7), France.
- April 1995– July 1995: *Visiting researcher*, Laboratory for Ultrastructure Research, Research Equipment Center, Hamamatsu University School of Medicine, Japan.
- October 1992 – April 1994 : *Research Assistant*,, Laboratory for Research and Development of Sensors, Institute of Materials Sciences, Vietnamese Academy of Science and Technology

Project Experience
Validating the Durability of Corrosion Resistant Mineral Admixture Concrete - The objectives of this research are to validate chloride diffusion coefficients of mineral admixture concrete mix designs currently specified by Caltrans for corrosion mitigation, and to verify the adequacy of existing measures to mitigate

corrosion caused by exposure to marine environments and deicing salt applications. Duration: March 2007 – March 2009.

An Autonomous and Self-Sustained Sensing System to Monitor Water Quality – The objective of the project is to develop an autonomous and self-sustained sensing system that *in-situ* monitors environmental parameters in water bodies near highways for assessing the impact of highway runoff on these water bodies. May 2007–Oct. 2008

Corrosion Inhibition Mechanisms at the Steel/Concrete Interface – The objectives of the project are to simulate the steel/concrete interface by physically depositing a nanometer-thin layer of steel on the concrete surface and to investigate the corrosion and corrosion inhibition mechanisms at the steel/concrete interface in the absence and presence of corrosion inhibitors. Funded by the U.S. Research and Innovative Technology Administration. Duration: May 2005 – Dec. 2006.

Publications - Selected

1. Nguyen, T.A., Lu, Y., Yang, X., and Shi, X. Carbon and Steel Surfaces Modified by *Leptothrix discophora* SP-6: Characterization and Implications. *Environmental Science & Technology*, 2007, in press.
2. Nguyen Tuan Dung, Nguyen Tuan Anh, Pham Minh Chau, Benoit Piro, Bernard Normand, Hisasi Takenouti, "Mechanism for Protection of Iron Corrosion by an Intrinsically Electronic Conducting Polymer", Journal of Electroanalytical Chemistry, 572 (2004), p.225-334.
3. Benoit Piro, Nguyen Tuan Anh, Jean Tanguy, Pham Minh Chau, "A Polyaminoquinone Film for Dopamine Entrapment and Delivery ", Journal of Electroanalytical Chemistry, 499(2001), p.103.
4. Nguyen Quang, Nguyen Thi Thai, Vu Van Binh, Nguyen Tuan Anh, " Study on phase structure and property of blend LDPE/NR in presence of inorganic additives", Vietnamese Journal of Science and Technology, Vol. XXXV, No. 4(1997), p.26-30
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6. Nguyen Tuan Anh, Vu Van Binh, "The Application of Scanning Electron Microscope and Energy Dispersive X-ray Spectroscopy for Investigation the Structure of some Environmental Sensors", Vietnamese Journal of Science and Technology, Vol. XXXIII, No. 5(1995), p.76-81.
7. Nguyen Tuan Anh, Yuzhuo Lu, Shizhe Song, Xianming Shi, "Carbon and steel surfaces modified by Leptothrix discophora SP-6: characterization and implications", Proceedings of 2007 Materials Research Society Spring Meeting, Symposium T (T5.10), April 9-13, 2007, San Francisco, CA, USA
8. Nguyen Tuan Anh, Philip G. Whitten, Geoffrey M. Spinks and Gordon G. Wallace, Producing Better DNA-Carbon nanotube Composite Film for Bio-electrodes, International Symposium on Electro-materials Science, Wollongong, 15-17th February 2006, Australia
9. Nguyen Tuan Anh, Le Thu Quy, Do Hung Manh, " Using Electron Microscopy Techniques to Study the Structure of the Conducting Polyaniline Nano-particles Contained Anti-corrosion Coating", Proceedings of the 6th Vietnam Conference on Physics, 23-25 Nov., 2005, CR2-P Th02
10. Nguyen Tuan Anh, Phan Ngoc Minh, Vu Van Binh, Nguyen Hong Quang, Structure and property research of Polyaniline nanotube Synthesized by Chemical Method Using Carbon nano-tube, Proceedings of the 6th Vietnam Conference on Physics, 23-25 Nov., 2005, CR2-P Th03
11. Nguyen Tuan Anh, Nguyen Van Khuong, Vu Van Binh, Pham Minh Chau,Yoshinori Muranaka, "Research and fabrication of conducting polyaniline nanoparticles by electrochemical and chemical methods", Proceedings of the International Symposium on Smart Materials, Nano-, and Micro-Smart Systems, Sydney, Dec. 12-15, 2004, paper 5648-78 (Proceedings of SPIE Volume: 5648, Smart Materials III, Ed. Alan R. Wilson, ISBN: 9780819456083, Feb 2005, p. 406-416.

12. Nguyen Tuan Anh, Nguyen Van Khuong, Vu Van Binh, Nguyen Le Hien, Dinh Mai Thanh,Yoshinori Muranaka, "Research and Fabrication of conducting polyaniline nanoparticles", Proceedings of the 9th Asia Pacific Physics Conference, Hanoi, Oct.25-31, 2004, Paper 10-65P
13. Nguyen Tuan Anh, Hisasi Takenouti, Yoshinori Muranaka, "Using Scanning Electrochemical Microscopy to Study the Anticorrosion Effect of Electro-polymerized Conducting Polymers on Iron", invited speaker, Proceedings of the 8th Asian Pacific Electron Microscopy Conference, Kanazawa, Japan, 7-11 June 2004, p.1335.
14. Nguyen Tuan Anh, Vu Van Binh, Pham Minh Chau, Hisasi Takenouti "Using SEM to Study the Influence of Geometric Structure on the Anti-corrosion Effect of some electro-polymerized Conducting Polymers on Iron", Proceedings of the 4th Asean Microscopy Conference, Hanoi, Vietnam, 5-6 Jan. 2004, p.199-204.
15. Nguyen Tuan Anh, Pham Minh Chau, Hisasi Takenouti, "A Mechanistic Investigation for Corrosion Protection of Iron by Polyaniline Coating using Localized Electrochemical Measurements", Proceedings of the 13th Asian Pacific Corrosion Control Conference, Osaka, Japan, 16-21 Nov. 2003, P12.
16. Nguyen Tuan Anh, Pham Minh Chau, Hisasi Takenouti, " Using the Local Electrochemical Impedance Spectroscopy (LEIS) to Study the Protective Ability of Conducting Polymer for Metals", Proceedings of the 4th Vietnam Conference on Solid State Physics, Vol. 3B (2004), p.464
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18. Nguyen Tuan Anh, Pham Minh Chau, Hisasi Takenouti, "Relation Between the Morphology and the Anti-corrosion Effect of Electro-polymerizied PANi-PDAN Conducting Polymer on Iron", Proceedings of the 8th Eurasia Conference on Chemical Sciences, Hanoi, Vietnam, 21-24/10/2003.
19. Nguyen Tuan Anh, Pham Minh Chau, Hisasi Takenouti, "Electro-polymerisation of Conducting Polyaniline on Iron in Oxalic Acid Solution for Anti-corrosion", Proceedings of the 8th Eurasia Conference on Chemical Sciences, Hanoi, Vietnam, 21-24, Oct., 2003
20. Nguyen Tuan Dung, Nguyen Tuan Anh, Pham Minh Chau, Benoit Piro, Michel Keddam, Hisasi Takenouti, "Protection Mechanism of Electronic Conducting Polymer on Iron Studied by Combination of Local Measurements : SVET, LEIS and Micro-raman Spectroscopy", Proceedings of The European Corrosion Congress 2003, 28 Sept. – 2 Oct. 2003, Budapest, Hungary, paper 44.
21. Nguyen Tuan Dung, Nguyen Tuan Anh, Pham Minh Chau, Benoit Piro, Michel Keddam, Hisasi Takenouti, " Protection Mechanism for Anti-corrosion of Iron by Conducting Polymer elaborated from Local Measurements", Proceedings of the Days for Electrochemistry of Poitiers, France, 3-6 June 2003, paper 8O112.
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24. Nguyen Tuan Anh, Vu Van Binh, "Some results of the Application of SEM and EDX in Study on Influence of Environment and Technology to Materials Properties", Proceedings of the 1st Vietnam Conference on Solid State Physics, Hue (1994), CT4.

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Education

2004-2006 M.S., *Statistics*, Montana State University – Bozeman (GPA 4.0)
1996-2000 B.S., *Russian*, Nanjing University, Nanjing, China

Key Qualifications

- Statistical analysis experience: paired difference tests, analysis of variance, linear regression and correlation, non-parametric tests, sampling distributions, multivariate analysis, biostatistics
- Project experience and interest in statistical analysis for transportation research
- Software: SAS, R, Minitab, Microsoft Word, Excel, Star office, Emacs

Employment History

3/1/07- Present *Research Associate*, Western Transportation Institute, Montana State University – Bozeman

11/01/06-2/28/07 *Research Aide*, Western Transportation Institute, Montana State University – Bozeman
- Statistical Analysis with programming in SAS and R

05/2006-07/2006 *Implementation Consultant*, Fast Enterprises, Denver, Colorado

Spring 2006 *Graduate Research Assistant*, Department of Mathematical Science, Montana State University – Bozeman
Project titled as "White bark pine blister rust infection rate estimation"
White bark pine monitoring group of Greater Yellowstone National Park. Duties included: ecological data analysis, sampling design, environmental statistics and programming with SAS, R together with statistical consulting

01/2004-12/2005 *Graduate Teaching Assistant*, Department of Mathematical Science, Montana State University – Bozeman
Instructor of statistics course: elementary statistics 216
Instructor of math course: m105
Tutor of math and statistics at math/statistics learning center

Project Experience

Validate Percent Wet Time – The objective of the project was: to develop an updated percent wet time table using recent hourly precipitation data from duration longer than 11 years to improve the wet percentage factors that are used to identify all locations that require safety improvements; to improve the accuracy of the percent wet time values by developing isoexposure contour maps to better identify high wet collision concentration locations in California. Duties include: literature review, quality control of hourly precipitation data, and handling of missing data. Funded by the California Department of Transportation. June 2006 to March 2008.

Huang, J., Wang, S., and Shi, X. Estimating the Wet-Pavement Exposure with Historical Precipitation Data in the State of California. *CD-ROM of the 87th Annual Meeting of Transportation Research Board*, Washington D.C., 2008, Paper number 08-2949.

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